

University of Alberta

*Changes in Moose and White-tailed Deer Abundance in Northeastern Alberta and the
Relationship to Cumulative Impacts*

by

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ABSTRACT

The relationship between ungulate abundance and the cumulative impacts resulting from industrial developments in northeastern Alberta is not well understood. In order to address this topic, aerial survey data of moose and white-tailed deer was analyzed. Analyses indicated that deer expanded north and were more numerous in 2001 than in 1969. Moose were less numerous in 2001 than in 1969 throughout northeastern Alberta. Moose abundance was negatively related to agriculture. There was also evidence of additive cumulative effects caused by agriculture and well density. White-tailed deer abundance was negatively related to the distance to urban centres, agriculture and cutblocks and positively related to road density. There was also evidence of additive cumulative effects caused by agriculture, well density and road density. However, the statistical models were not very robust, suggesting that the cumulative impacts considered are not likely the main drivers of moose and white-tailed deer abundance and distribution.

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TABLE OF CONTENTS

Chapter 1: General Introduction and Thesis Overview

Background and Rationale.....	1
Literature Cited.....	4

*Chapter 2: Changes in Moose (*Alces alces*) and White-tailed Deer (*Odocoileus virginianus*) Counts and Distribution in Northeastern Alberta from 1969 to 2001*

Introduction.....	8
Methods.....	9
Study Area.....	9
Ungulate Counts.....	10
Survey Variables.....	10
Statistical Analysis.....	12
Results.....	14
Survey Method Summary and Analysis.....	14
Analysis of Ungulate Counts and Distribution.....	15
Discussion.....	17
Literature Cited.....	20

*Chapter 3: Moose (*Alces alces*) and White-tailed Deer (*Odocoileus virginianus*) Abundance in Relation to Cumulative Impacts: A Spatial Analysis*

Introduction.....	46
Methods.....	48
Study Area.....	48
Ungulate Abundance.....	49
Landuse Variables.....	49
Distance Variables.....	50
Habitat Variables.....	51
Additional Variables.....	51
Statistical Analysis.....	51
Results.....	54
Composition of Landscape and Correlation Analysis.....	54
Analysis of Moose Abundance.....	57
Analysis of White-tailed Deer Abundance.....	58
Discussion.....	59
Literature Cited.....	64

Chapter 4: General Conclusions and Implications

Research Summary and Conclusions.....	92
Management Recommendations.....	93
Literature Cited.....	94

LIST OF FIGURES

- Figure 1.1: Province of Alberta. Wildlife Management Units outlined in black. Dark grey shaded Wildlife Management Units indicate general area of study in northeastern Alberta. Striped areas indicate protected areas. Black areas indicate urban centres.....6
- Figure 2.1: Northeastern Alberta study area. Inset shows location in Alberta. Townships surveyed for moose and white-tailed deer by Alberta Sustainable Resource Development from 1969 to 2001 in dark grey. Black areas indicate urban centres and striped areas indicate protected areas.....24
- Figure 2.2: Annual number of ungulate surveys in northeastern Alberta. Collected from Alberta Sustainable Resource Development for 1969 to 2001.....25
- Figure 2.3: Method types utilized by Alberta Sustainable Resource Development to conduct aerial ungulate surveys in northeastern Alberta from 1969 to 2001. Methods displayed over a township grid, with each large square representing a township and smaller squares representing sections. A) Directed surveys. B) Transect Surveys. C) Quadrat Surveys. D) Polygon Surveys.....26
- Figure 2.4: Survey method and aircraft types used by Alberta Sustainable Resource Development to conduct aerial ungulate surveys in northeastern Alberta from 1969 to 2001.....27
- Figure 2.5: Comparison of observed proportions of moose counts from Alberta Sustainable Resource Development ungulate surveys flown in northeastern Alberta (1969-2001) to negative binomial and Poisson distributions.....28
- Figure 2.6: Comparison of observed proportions of white-tailed deer counts from Alberta Sustainable Resource Development ungulate surveys flown in northeastern Alberta (1969-2001) to negative binomial and Poisson distributions.....29
- Figure 2.7: Average area surveyed within a township by year of survey for Alberta Sustainable Resource Development ungulate surveys flown in northeastern Alberta from 1969 to 2001.....30
- Figure 2.8: Location surveyed (expressed by township and range coordinates) by year of survey for Alberta Sustainable Resource Development ungulate surveys flown in northeastern Alberta from 1969 to 2001.....31
- Figure 2.9: Three-dimensional graph of average predicted moose counts in northeastern Alberta by township and year of survey for study period from 1969 to 2001. Higher township numbers indicate a location further north. Township 54 is the most southerly township in the study area at 53.6°N latitude. Township 126 is the most northerly township in the study area at 59.9°N latitude.....32

- Figure 2.10: Three-dimensional graph of average predicted moose counts in northeastern Alberta by range and year of survey for study period from 1969 to 2001. Higher range numbers indicate a location further west. Range 1 is the most easterly range in the study area at 110.0°W longitude. Range 27 is the most westerly range in the study area at 113.9°W longitude.....33
- Figure 2.11: Presence-absence map of moose in northeastern Alberta based on surveys conducted by Alberta Sustainable Resource Development from 1969 to 1984. Inset shows location in Alberta. Dark grey indicates townships where moose are present. Light grey indicates townships where moose are absent. Black areas indicate urban centres and striped areas indicate protected areas.....34
- Figure 2.12: Presence-absence map of moose in northeastern Alberta based on surveys conducted by Alberta Sustainable Resource Development from 1985 to 2001. Inset shows location in Alberta. Dark grey indicates townships where moose are present. Light grey indicates townships where moose are absent. Black areas indicate urban centres and striped areas indicate protected areas.....35
- Figure 2.13: Residual plot of constant information scale fitted values of moose counts against Anscombe residual values for the analysis of moose counts within sample sites in northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1969 to 2001.....36
- Figure 2.14: Histogram of moose count Anscombe residuals for the analysis of moose counts within sample sites in northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1969 to 2001.....37
- Figure 2.15: Three-dimensional graph of average predicted white-tailed deer in northeastern Alberta counts by township and year of survey for study period from 1969 to 2001. Higher township numbers indicate a location further north. Township 54 is the most southerly township in the study area at 53.6°N latitude. Township 126 is the most northerly township in the study area at 59.9°N latitude. Note that the direction of the axes have changed in relation to previous figures in order to make the visual representation of the trends in the data more clear.....38
- Figure 2.16: Presence-absence map of white-tailed deer in northeastern Alberta based on surveys conducted by Alberta Sustainable Resource Development from 1969 to 1984. Inset shows location in Alberta. Dark grey indicates townships where deer are present. Light grey indicates townships where deer are absent. Black areas indicate urban centres and striped areas indicate protected areas.....39
- Figure 2.17: Presence-absence map of white-tailed deer in northeastern Alberta based on surveys conducted by Alberta Sustainable Resource Development from 1985 to 2001. Inset shows location in Alberta. Dark grey indicates townships where deer are present. Light grey indicates townships where deer are absent. Black areas indicate urban centres and striped areas indicate protected areas.....40

- Figure 2.18: Residual plot of constant information scale fitted values of white-tailed deer counts against Anscombe residual values for the analysis of white-tailed deer counts within sample sites in northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1969 to 2001.....41
- Figure 2.19: Histogram of white-tailed deer count Anscombe residuals for the analysis of white-tailed deer counts within sample sites in northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1969 to 2001.....42
- Figure 3.1: Northeastern Alberta study area and sample sites based on ungulate surveys conducted by Alberta Sustainable Resource Development from 1998 to 2002. Inset shows location in Alberta. Sample sites not included in modeling are indicated by white polygons. Sample sites for the analysis of high agricultural coverage (southern sub-region) are indicated by dark grey polygons. Sample sites for the analysis of low agricultural coverage (northern sub-region) are indicated by light grey polygons. Black areas indicate urban centres and striped areas indicate protected areas.....69
- Figure 3.2: Results from regression analyses of moose abundance for the southern sub-region. Moose abundance derived from Alberta Sustainable Resource Development surveys (1998-2002). Partial regression plots shown. P-values, partial R^2 and coefficient listed below. A) Road density ($p=0.60$, $R^2=0.009$, $b=-0.01$). B) Linear density ($p=0.83$, $R^2=0.002$, $b=0.001$). C) Well density ($p=0.22$, $R^2=0.044$, $b=-0.01$). D) Agricultural coverage ($p=0.003$, $R^2=0.227$, $b=-0.10$). E) Distance to native reserve ($p=0.50$, $R^2=0.014$, $b=-0.0004$). F) Distance to urban centre ($p=0.46$, $R^2=0.017$, $b=0.0004$). G) Distance to major highway ($p=0.99$, $R^2<0.0001$, $b=0.00001$).....70
- Figure 3.3: Results from regression analyses of moose abundance for the northern sub-region. Moose abundance derived from Alberta Sustainable Resource Development surveys (1998-2002). Partial regression plots shown. P-values, partial R^2 and coefficient listed below. A) Road density ($p=0.52$, $R^2=0.017$, $b=-0.05$). B) Linear density ($p=1.00$, $R^2<0.0001$, $b=-0.0001$). C) Well density ($p=0.37$, $R^2=0.028$, $b=-0.06$). D) Agricultural coverage ($p=0.83$, $R^2=0.002$, $b=0.08$). E) Distance to native reserve ($p=0.67$, $R^2=0.008$, $b=-0.0005$). F) Distance to urban centre ($p=0.41$, $R^2=0.026$, $b=-0.001$). G) Distance to major highway ($p=0.66$, $R^2=0.008$, $b=-0.0004$). H) Cutblock coverage ($p=0.67$, $R^2=0.008$, $b=-0.30$).....72
- Figure 3.4: Residual plot of fitted moose values against residual values for the analysis of the relationship between moose abundance and landuse variables within sample sites in the southern sub-region of northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1998 to 2002.....74
- Figure 3.5: Residual plot of fitted moose values against residual values for analysis of relationship between moose abundance and landuse variables within sample sites in the northern sub-region of northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1998 to 2002.....75

- Figure 3.6: Histogram of moose abundance residuals for the analysis of the relationship between moose abundance and landuse variables within sample sites in the southern sub-region of northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1998 to 2002.....76
- Figure 3.7: Histogram of moose abundance residuals for the analysis of the relationship between moose abundance and landuse variables within sample sites in the northern sub-region of northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1998 to 2002.....77
- Figure 3.8: Results from regression analyses of white-tailed deer abundance for the southern sub-region. Deer abundance derived from Alberta Sustainable Resource Development surveys (1998-2002). Partial regression plots shown. P-values, partial R^2 and coefficient listed below. A) Road density ($p=0.005$, $R^2=0.220$, $b=0.72$). B) Linear density ($p=0.09$, $R^2=0.075$, $b=0.10$). C) Well density ($p=0.76$, $R^2=0.003$, $b=-0.04$). D) Agricultural coverage ($p=0.01$, $R^2=0.158$, $b=-0.85$). E) Distance to native reserve ($p=0.90$, $R^2=0.0006$, $b=-0.001$). F) Distance to urban centre ($p=0.04$, $R^2=0.118$, $b=-0.01$). G) Distance to major highway ($p=0.87$, $R^2=0.0008$, $b=-0.003$).....78
- Figure 3.9: Results from regression analyses of white-tailed deer abundance for the northern sub-region. Deer abundance derived from Alberta Sustainable Resource Development surveys (1998-2002). Partial regression plots shown. P-values, partial R^2 and coefficient listed below. A) Road density ($p=0.64$, $R^2=0.009$, $b=0.01$). B) Linear density ($p=0.86$, $R^2=0.001$, $b=0.002$). C) Well density ($p=0.94$, $R^2=0.0002$, $b=0.003$). D) Agricultural coverage ($p=0.61$, $R^2=0.010$, $b=0.07$). E) Distance to native reserve ($p=0.13$, $R^2=0.084$, $b=-0.0007$). F) Distance to urban centre ($p=0.08$, $R^2=0.108$, $b=-0.0004$). G) Distance to major highway ($p=0.14$, $R^2=0.077$, $b=0.0006$). H) Cutblock coverage ($p=0.01$, $R^2=0.218$, $b=-0.63$).....80
- Figure 3.10: Residual plot of fitted white-tailed deer values against residual values for analysis of relationship between white-tailed deer abundance and landuse variables within sample sites in the southern sub-region of northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1998 to 2002.....82
- Figure 3.11: Residual plot of fitted white-tailed deer values against residual values for analysis of relationship between white-tailed deer abundance and landuse variables within sample sites in the northern sub-region of northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1998 to 2002.....83
- Figure 3.12: Histogram of white-tailed deer abundance residuals for the analysis of the relationship between white-tailed deer abundance and landuse variables within sample sites in the southern sub-region of northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1998 to 2002.....84
- Figure 3.13: Histogram of white-tailed deer abundance residuals for the analysis of the relationship between white-tailed deer abundance and landuse variables within sample sites in the northern sub-region of northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1998 to 2002.....85

LIST OF TABLES

Table 1.1: Total number of ungulates harvested in northeastern Alberta from 1985 to 2000. Derived from Harvest and Effort reports from Alberta Sustainable Resource Development using data from Wildlife Management Units highlighted in Figure 1.1 (ASRD 1985-2000).....	7
Table 2.1: Independent variables considered in the analysis of changes in moose and white-tailed deer counts, as derived from surveys conducted by Alberta Sustainable Resource Development from 1969 to 2001. Mean, median and range provided for continuous variables and the number of replicates listed for categorical variables....	43
Table 2.2: Percent changes in predicted moose and white-tailed deer counts, in relation to the grand mean and holding all other variables constant, given different aerial survey methods from surveys conducted in northeastern Alberta by Alberta Sustainable Resource Development from 1969 to 2001.....	43
Table 2.3: Negative binomial regression results for analysis of relationship between the counts of moose, determined by aerial surveys flown by Alberta Sustainable Resource Development in northeastern Alberta (1969-2001), and survey variables ($n=3604$; $p<0.001$; McFadden's Adjusted $R^2=0.068$). 95% confidence interval for coefficient provided in brackets.....	44
Table 2.4: Negative binomial regression results for analysis of relationship between counts of white-tailed deer, determined by aerial surveys flown by Alberta Sustainable Resource Development in northeastern Alberta (1969-2001), and survey variables ($n=3604$; $p<0.001$; McFadden's Adjusted $R^2=0.201$). 95% confidence interval for coefficient provided in brackets.....	45
Table 3.1: Correlation matrix of landuse variables for all northeastern Alberta sample sites surveyed by Alberta Sustainable Resource Development from 1998 to 2002.....	86
Table 3.2: Median and range of percent area coverage of habitat and landuse variables within all northeastern Alberta sample sites surveyed by Alberta Sustainable Resource Development from 1998 to 2002. Regional data represents the values for townships across the northeast region of Alberta and is provided in brackets. Derived from Alberta Ground Cover Classification (2000).....	86
Table 3.3: Median and range of proportion of habitat and landuse variables within southern and northern sub-region sample sites in northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1998 to 2002. Northern data is provided in brackets. Derived from Alberta Ground Cover Classification (2000).....	86
Table 3.4: Median and range of landuse and distance variables within all northeastern Alberta sample sites surveyed by Alberta Sustainable Resource Development from 1998 to 2002. Regional data for northeastern Alberta is provided in brackets. Derived from Alberta Base Features GIS layers (2000).....	87

Table 3.5:	Median and range of landuse and distance variables within southern and northern sub-region sample sites of northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1998 to 2002. Northern data is provided in brackets. Derived from Alberta Base Features GIS layers (2000).....	87
Table 3.6:	Correlation matrix of landuse, spatial and habitat variables for sample sites surveyed in the southern sub-region of northeastern Alberta by Alberta Sustainable Resource Development from 1998 to 2002.....	87
Table 3.7:	Regression results for analysis of relationship between moose abundance and landuse variables within sample sites in the southern sub-region of northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1998 to 2002 (n=45; $p<0.001$; adjusted $R^2=0.71$). 95% confidence interval range for coefficient provided in brackets. Expected change refers to the increase or decrease expected in moose/km ² over the range of data for the region.....	88
Table 3.8:	Regression results for the analysis of relationship between moose abundance and landuse variables within sample sites in the northern sub-region of northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1998 to 2002 (n=36; $p=0.0001$; adjusted $R^2=0.61$). 95% confidence interval range for coefficient provided in brackets. Expected change refers to the increase or decrease expected in moose/km ² over the range of data for the region.....	89
Table 3.9:	Regression results for analysis of relationship between white-tailed deer abundance and landuse variables within sample sites in the southern sub-region of northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1998 to 2002 (n=45; $p<0.001$; adjusted $R^2=0.50$). 95% confidence interval for coefficient provided in brackets. Expected change refers to the increase or decrease expected in deer/km ² over the range of data for the region.....	90
Table 3.10:	Regression results for the analysis of relationship between white-tailed deer abundance and landuse variables within sample sites in the northern sub-region of northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1998 to 2002 (n=36; $p<0.001$; adjusted $R^2=0.86$). 95% confidence interval for coefficient provided in brackets. Expected change refers to the increase or decrease expected in deer/km ² over the range of data for the region.....	91

General Introduction and Thesis Overview

Background and Rationale

Addressing the cumulative impacts of landuse disturbances has become increasingly important in recent years, as managers have begun to recognize that multiple disturbances are beginning to accumulate and may be having impacts that exceed that which would be predicted based on individual impacts. Cumulative impacts can arise from the increasing pressures of a single disturbance, as well as the additive and/or interactive effects of multiple disturbances (Bonnell and Storey 2000). The scope of cumulative impacts can vary from considering natural disturbances, such as floods and fire, to inclusion of only anthropogenic disturbances. While natural disturbances certainly play an important role in forming landscape patterns, anthropogenic disturbances may be more threatening to species persistence, given that some of the most lasting disturbances to the landscape are human induced (Lawlor 2003). For example, agricultural lands are rarely returned to their natural state after conversion. As well, forested lands are continually managed for harvest, which can result in truncated age distributions and changes in patch size (Fall et al. 2004, Fitzsimmons 2003). Anthropogenic disturbances lead to changes in disturbance regimes and impact ecosystem processes through habitat loss and fragmentation (White and Harrod 1997).

Determining changes in moose (*Alces alces*) and white-tailed deer (*Odocoileus virginianus*) abundance and distribution, as well as the relationships between cumulative impacts and moose and white-tailed deer abundance is of particular interest in northeastern Alberta, the location of this study (Figure 1.1). This region has experienced rapid industrial development in recent years (Schneider 2002). While dominated by the boreal forest, this region also contains parkland forest and agricultural areas in the southern portion (AEP 1998). Rapid landuse change in northeastern Alberta, as a result of anthropogenic disturbances, has mostly come from forest

harvest allocation and the expansion of petroleum industry developments. In 1991, the Alberta Provincial Government allocated a forest management area located in northeastern Alberta to Alberta-Pacific Forest Industries encompassing approximately 58,000 km² (ALPAC 2005). High oil and gas prices in the 1970s and 1990s resulted in rapid increases in drilling rates of new oil and gas wells throughout the province (Schneider 2002). Associated with wellsites was the expansion of a network of linear features. As well, the oilsands extraction near Fort McMurray, originally initiated in 1967, began to rapidly develop in the 1990s with high oil prices (Schneider 2002). With both forestry and oil and gas developments also came the expansion of road networks. In addition to these industrial developments, there has been continued agricultural encroachment into forested areas (AEP 1998). As well, settlement in the northeast was very limited in the first half of the century, with rapid population growth only occurring after 1960, primarily because of the expansion of the petroleum industry (Schneider 2002).

Ungulates have significant effects on vegetation composition and basic ecosystem processes (Danell et al. 2003, Kie et al. 2003, Seagle 2003, Weisberg and Bugmann 2003). Ungulates can influence plant standing crop, species richness of forbs and distribution of shrub species, in addition to modifying rates of nutrient turnover, competitive interactions among plant species, and rates and trajectories of successional pathways. As well, ungulates affect society in a number of ways. Ungulates are important for the provision of recreational hunting opportunities, as well as the aesthetic value brought about from wildlife viewing. However, ungulates can also bring costs to society through crop depredation (Van Tassell et al. 1999), damage to seedlings associated with forestry operations (Horsley et al. 2003) and vehicular accidents (Bennett 1991). Additionally, there are concerns about the potential for ungulates to spread disease to livestock (Palmer et al. 2004).

In northeastern Alberta, moose and white-tailed deer are the most popular ungulate game species, exceeding the harvest rates of both mule deer (*Odocoileus hemionus*) and elk (*Cervus*

elaphus), with white-tailed deer making up 81% of all ungulates harvested in the northeast from 1985 to 2000 and moose making up 16% (Table 1.1). Moose are primarily forest dwellers and feed mostly on the leaves and stems of trees and shrubs (Stelfox and Stelfox 1993). In contrast, white-tailed deer are adapted to both open and forested habitats (Stelfox and Stelfox 1993). White-tailed deer are considered mixed feeders, foraging on crops, grasses, forbs and woody plants (Stelfox and Stelfox 1993). Given the demand for these game species, as well as their importance in influencing society, vegetation composition and basic ecosystem processes, any changes in the distribution or abundance of moose and white-tailed deer or potential relationships with cumulative impacts is of importance for managers and society alike.

The objectives of my study are two-fold:

Objective I: To determine any spatial and temporal changes in moose and white-tailed deer counts in northeastern Alberta over the last 30 years, while taking into consideration the effects of variable survey methodology. Alberta Sustainable Resource Development has been surveying ungulates since the 1960s. The intent of this analysis is to indicate how moose and white-tailed deer counts have changed over time and space, after controlling for the method used for conducting surveys (Chapter 2).

Objective II: To determine recent relationships between cumulative impacts and moose and white-tailed deer abundance in northeastern Alberta. This analysis will indicate how moose and white-tailed deer abundance responds in relation to cumulative impacts through a spatial analysis. Cumulative impacts will be addressed through consideration of increasing intensities of individual disturbances, as well as the additive and multiplicative effects of multiple disturbances (Chapter 3).

In Chapter 4, I present my general conclusions and discuss management implications.

Literature Cited

- Alberta Environmental Protection (AEP). 1998. The Boreal Forest Natural Region of Alberta. Alberta Environmental Protection, Edmonton, Alberta, Canada. 313 pp.
- Alberta-Pacific Forest Industries (ALPAC). 2005. About Alberta Pacific Forest Industries Inc. http://www.alpac.ca/About_AI-Pac/About.htm
- Alberta Sustainable Resource Development (ASRD). 1985-2000. Harvest and Effort by Resident Hunters. Alberta Sustainable Resource Development, Edmonton, Alberta, Canada.
- Bennett, A.F. 1991. Roads, roadsides and wildlife conservation: a review. Pp. 99-117 in Saunders, D.A. and R.J. Hobbs, eds. Nature Conservation 2: The Role of Corridors. Surrey Beatty & Sons, Chipping Norton, Australia. 442 pp.
- Bonnell, S. and K. Storey. 2000. Addressing cumulative effects through strategic environmental assessment: A case study of small hydro development in Newfoundland, Canada. *Journal of Environmental Assessment Policy and Management*. 2: 477-499.
- Danell, K., R. Bergstrom, L. Edenius and G. Ericsson. 2003. Ungulates as drivers of tree populations dynamics at module and genet levels. *Forest Ecology and Management*. 181: 67-76.
- Fall, A., M.J. Fortin, D.D. Kneeshaw, S. H. Yamasaki, C. Messier, L. Bouthillier and C. Smyth. 2004. Consequences of various landscape-scale ecosystem management strategies and fire cycles on age-class structure and harvest in boreal forests. *Canadian Journal of Forest Research*. 34: 310-322.
- Fitzsimmons, M. 2003. Effects of deforestation and reforestation on landscape spatial structure in boreal Saskatchewan, Canada. *Forest Ecology and Management*. 174: 577-592.
- Horsley, S.B., S.L. Stout and D.S. DeCalesta. 2003. White-tailed deer impact on the vegetation dynamics of a northern hardwood forest. *Ecological Applications*. 13: 98-118.

- Kie, J.G., T. Bowyer and K.M. Stewart. 2003. Ungulates in western coniferous forests: habitat relationships, population dynamics, and ecosystem processes. Pp. 296-340 in Zabel, C.J. and R.G. Anthony, eds. *Mammal Community Dynamics: Management and Conservation in the Coniferous Forests of Western North America*. Cambridge University Press, Cambridge, U.K. 709 pp.
- Lawlor, T.E. 2003. Faunal composition and distribution of mammals in western coniferous forests. Pp. 41-80 in Zabel, C.J. and R.G. Anthony, eds. *Mammal Community Dynamics: Management and Conservation in the Coniferous Forests of Western North America*. Cambridge University Press, Cambridge, U.K. 709 pp.
- Palmer, M.V., W.R. Waters and D.L. Whipple. 2004. Investigation of the transmission of *Mycobacterium bovis* from deer to cattle through indirect contact. *American Journal of Veterinary Research*. 65: 1483-1489.
- Schneider, R.R. 2002. *Alternative Futures: Albertas Boreal Forest at the Crossroads*. The Federation of Alberta Naturalists, Edmonton, Alberta, Canada. 152 pp.
- Seagle, S.W. 2003. Can ungulates foraging in a multiple-use landscape alter forest nitrogen budgets? *Oikos*. 103: 230-234.
- Stelfox, J.B. and J.G. Stelfox. 1993. Distribution. Pp. 45-61 in Stelfox, J.B., ed. *Hoofed Mammals of Alberta*. Lone Pine Publishing, Edmonton, Alberta, Canada. 241 pp.
- Weisberg, P.J. and H. Bugmann. 2003. Forest dynamics and ungulate herbivory: from leaf to landscape. *Forest Ecology and Management*. 181: 1-12.
- White, P.S. and J. Harrod. 1997. Disturbance and Diversity in a Landscape Context. Pp. 128-159 in Bissonette, J.A., ed. *Wildlife and Landscape Ecology: Effects of Pattern and Scale*. Springer-Verlag New York Inc., New York, U.S.A. 410 pp.
- Van Tassell, L.W., C. Phillips and B. Yang. 1999. Depredation claim settlements in Wyoming. *Wildlife Society Bulletin*. 27: 479-487.

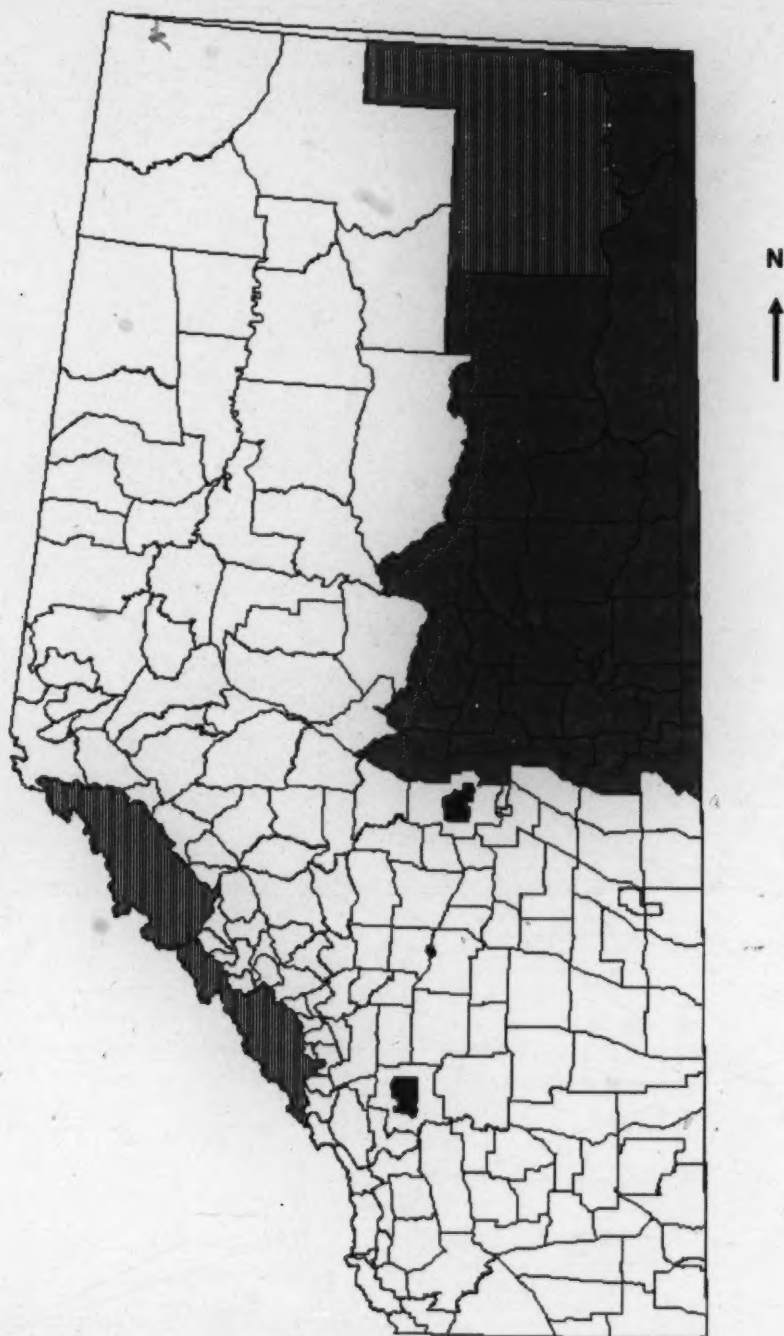


Figure 1.1: Province of Alberta. Wildlife Management Units outlined in black. Dark grey shaded Wildlife Management Units indicate general area of study in northeastern Alberta. Striped areas indicate protected areas. Black areas indicate urban centres.

Table 1.1: Total number of ungulates harvested in northeastern Alberta from 1985 to 2000.
Derived from Harvest and Effort reports from Alberta Sustainable Resource Development using
data from Wildlife Management Units highlighted in Figure 1.1 (ASRD 1985-2000).

Year	White-tailed Deer Harvested	Moose Harvested	Elk Harvested	Mule Deer Harvested
1985	3660	910	0	121
1986	6109	1764	0	154
1987	4374	1548	7	144
1988	7179	2214	36	183
1989	7447	1610	23	194
1990	5635	1173	22	126
1991	7388	1725	18	208
1992	6166	913	11	157
1993	6613	1013	23	216
1994	7078	1077	0	320
1995	10342	1320	17	446
1996	8035	1449	26	365
1998	9773	1492	34	376
1999	7783	1090	49	334
2000	9155	1327	51	470

Changes in Moose (*Alces alces*) and White-tailed Deer (*Odocoileus virginianus*) Counts and Distribution in Northeastern Alberta from 1969 to 2001

Introduction

The location and abundance of species are determined by a variety of factors, including habitat preferences, dispersal abilities, species inter- and intra-relationships and abiotic factors (Krebs 2001). Anthropogenic developments have altered the distribution and abundance of species both directly through introductions and extinctions and indirectly through habitat modification. Species that differ with respect to habitat requirements and other natural history traits will perceive and respond to landscape patterns in different ways (Lawlor 2003). Thus, the creation of new habitats or alteration of existing ones can result in the extirpation of some species and the expansion of distribution and abundance of other species.

Determining changes in the counts and distribution of moose (*Alces alces*) and white-tailed deer (*Odocoileus virginianus*) populations in northeastern Alberta is important for successful management of these popular game species. Since harvest estimates began in 1985, moose and white-tailed deer have been the most hunted ungulate species in northeastern Alberta (ASRD 1985-2000). Thus, any factors that influence the population dynamics of these species are likely to be of concern to managers and hunters. Equally important is the effect that these populations have on ecosystem dynamics. For example, as the abundance of moose and white-tailed deer increases, wolf populations may increase, adding additional predatory pressure to sensitive species like the woodland caribou (Gunson et al. 1993, Seip 1995). As well, white-tailed deer may serve as a significant conduit of nitrogen among ecosystems (Seagle 2003), while moose have been associated with influencing the development, distribution and density of vegetation patches, nitrogen cycling rates, as well as the development of higher order patterns across the larger landscape (Moen et al. 1998, Pastor et al. 1998).

Despite the importance of white-tailed deer and moose, potential long-term changes in their regional counts and distribution in northeastern Alberta have not previously been

investigated. Provincial population estimates from 1902 to 1990 suggest that moose populations are decreasing (Stelfox and Stelfox 1993b). In Saskatchewan, Christmas Mammal Counts have documented the increase of all ungulates within the province and the expansion of the moose range into the plains (Smith 2004). An increase in the abundance of white-tailed deer and their subsequent overabundance has become a concern across eastern North America (Augustine and de Calesta 2003, Van Deelen 1996).

Alberta Sustainable Resource Development has been monitoring ungulates since the 1960s and over this timeframe survey techniques have changed. Therefore, in considering changes in moose and white-tailed deer counts and distribution over time, it is important to consider factors that may have influenced the observation of these species, such as survey methods and aircraft type. Quadrat surveys typically return higher population estimates than transect surveys and intensive searches with a circling flight pattern have a higher detection rate than transect flights (Peterson and Page 1993, Pojar et al. 1994). As well, helicopters can be a more effective aircraft for aerial surveys than fixed-wing, often returning higher estimates of animal abundance (Crete et al. 1986).

The objective of my study was to determine spatial and temporal changes in moose and white-tailed deer counts from 1969 to 2001 in northeastern Alberta, while controlling for a changing sampling methodology. I used aerial surveys of these species, conducted by Alberta Sustainable Resource Development, to derive ungulate counts.

Methods

Study Area

All data collection was limited to the boreal forest of northeastern Alberta (Figure 2.1) (AEP 1998). The area considered extended from longitude 110.0°W to 114.0°W and north of latitude 53.4°N to 60.0°N. Alberta is overlaid with a grid composed of townships and ranges. A

township is a measure of northing, increasing from 1 (49.0°N latitude) to 126 (60.0°N latitude). A range is a measure of easting between the 4th, 5th and 6th meridians (110.0°W, 114.0°W and 118.0°W longitude, respectively). The number of ranges varies depending on the latitude and in northeastern Alberta range increases from 1 (110.0°W longitude) to 27 (114.0°W longitude). Each unit is 93.2 km², measuring approximately 9.7 km on each side. Each unit is further divided into 36 sections, each 2.6 km².

Ungulate Counts

Moose and white-tailed deer counts were derived from 166 aerial surveys conducted by Alberta Sustainable Resource Development between 1969 and 2001 (Figure 2.2). These aerial surveys were primarily conducted in the winter months (November to February) and were used to obtain estimates of ungulate abundance within study areas that ranged in size from approximately 275 km² to over 42,000 km². However, surveys were also conducted to investigate areas of concentrated crop depredation and to monitor relocated ungulates. Furthermore, aerial surveys conducted to determine predator abundance often noted ungulates. From the data available, I calculated the number of ungulates observed within the boundaries of a township (93.2 km²), though the actual area surveyed within the townships varied from below 2.6 km² to 49.8 km² and averaged 9.6 km². The minimum area accepted for inclusion in the analysis was set at 2.6 km², as this has historically been used in conducting intensive aerial surveys and quadrat flights have been based on surveying parcels of land this size (Timmerman 1974). In some cases, individual townships were revisited from 1969 to 2001 and this was accounted for in my analysis. In total, 3604 samples were used in my analysis.

Survey Variables

Variables related to the aerial ungulate surveys included year, location, mean township and range surveyed within each year, survey method and area surveyed (Table 2.1). These

variables were derived from the Alberta Sustainable Resource Development survey reports. Year was defined by the winter in which the survey was conducted and was standardized such that the first year of surveys (1969) was given the value of one. Location was recorded by township and range coordinates. To account for inter-annual variation in where surveys occurred, the mean township and range of all sample sites surveyed within each survey year were recorded. Aerial survey methods included directed flights, transects, quadrats and polygons (Figure 2.3). Directed flight surveys were used to locate known concentrations of ungulates or were flown along rivers. Directed flights did not follow a predetermined flight pattern but typically used an observing width of 200m on either side of the aircraft. Transect surveys were flown in a uniform linear pattern, with a typical observing width of 200m on either side of the aircraft. For both directed and transect flights, I counted ungulates observed on the border of two townships in both townships. Quadrats were surveys flown for complete coverage within one to several sections of land within a township, each 2.6 km², across several townships. Where more than one quadrat was surveyed within a township in a single survey, the counts of ungulates and the area surveyed were added together. Polygon surveys were stratified by either habitat or density of ungulates depending on the year of the survey. Before 1993, polygon surveys consisted of irregularly shaped survey blocks, flown for complete coverage within a township and across several townships. After 1993, polygons were laid out within wildlife management units (WMUs) on a latitude-longitude grid and were selected and surveyed based on a modified Gasaway technique (Gasaway et al. 1986). Ungulate surveys conducted using fixed-wing aircraft were used to stratify the WMUs into high, medium and low categories of relative abundance. Polygons for each strata were then randomly selected and resurveyed with a helicopter to get an abundance estimate. Polygons that had boundaries overlapping multiple townships were excluded from the analysis. Inter-annual variation existed in the survey methods used from 1969 to 2001, though all survey methods overlapped in their use (Figure 2.4). All surveys were flown by either fixed-wing or

rotary aircraft. While usually these surveys were flown with the intent of obtaining a random or uniform sample, some directed surveys sought out concentrations of ungulates along rivers or in areas of concern. In more recent years, the number of surveys available for analysis has been reduced due to reductions in funding and lack of available documentation. I calculated the area surveyed for directed and transect surveys by multiplying the linear distance covered within a township by the observation width, which was typically recorded in the survey reports. The area surveyed for quadrat and polygon surveys within a township were taken from the Alberta Sustainable Resource Development ungulate survey reports.

Statistical Analysis

Before modelling, I calculated correlation coefficients between all of the independent variables. I considered any combination of variables exhibiting a correlation coefficient of ≥ 0.70 highly correlated (Cohen et al. 2000) and chose not to include these variables in the model together. However, none of the variables included in the moose and white-tailed deer models were highly correlated, therefore all were included in the overall model.

To determine whether the counts and distribution of ungulates have changed in northeastern Alberta, I modeled moose and white-tailed deer counts separately using negative binomial regression based on the over-dispersed distributions of the ungulate counts (Figures 2.5 and Figure 2.6). Given that several townships were surveyed on multiple occasions, models included the robust cluster command, which specifies that the observations are independent across groups (clusters) but not necessarily within groups (StataCorp 2004). Clustering was used in order to obtain robust variance estimates that accounted for temporal autocorrelation. A backwards-stepwise modeling approach was used to remove variables from the overall model until all variables remaining in the model were significant to $p < 0.15$ (Hosmer and Lemeshow 2000). At the end of the procedure, each dropped variable was re-entered into the model to check for confounding variables (Hosmer and Lemeshow 2000). Any variable re-entered that resulted in

a coefficient change of $\geq 20\%$ in the model variables was retained in the model. Non-linearities in township, range and year were considered by including the quadratics of each variable and testing for significance. Interactions between the variables of township, range and year were also considered. All analyses were conducted in STATA (StataCorp 2004). Three-dimensional graphs were constructed in SigmaPlot to visually display the spatial and temporal relationships (SYSTAT 2001). In plotting the graphs, the negative binomial regression equation resulting from the model was used to obtain the predicted average ungulate counts for the z-axis. Mean values of all continuous variables not included in the interaction were used to create the equation. Finally, residual plots of Anscombe residuals against constant-information scale (CIS) fitted values and histograms of the Anscombe residuals were created to assess the fit of the final models. Anscombe residuals were used as to obtain a distribution that was approximately normal (Hardin and Hilbe 2001). Fitted values were transformed to the constant-information scale using the formula: $CIS \text{ fitted values} = 2 * \sqrt{\text{fitted values}}$ (Nelder 1990).

To ensure that the patterns I observed were solely due to statistical method, I conducted another conservative analysis. I Box-Cox transformed the values obtained from dividing counts by the area surveyed within a township and regressed the transformed values against method. The residuals of this model were then regressed against the remaining independent variables. This approach could only be conducted for moose, given that transformation of the white-tailed deer data was not possible due to its highly skewed nature. However, for moose, the analysis yielded the same significant independent variables, non-linearities and interactions as obtained using negative binomial regression. Only the results from the negative binomial regression approach are presented here.

Results

Survey Method Summary and Analysis

In general, the average area surveyed within townships, between 1969 and 2001, ranged from an average around 5 km² to upwards of 40 km² (Figure 2.7). As well, the location of surveys shifted so that surveys in more recent years tended to occur in more southern areas between townships 60 and 70, as opposed to surveys in the early 1970s that averaged locations at township 80 to 90 (Figure 2.8). However, surveys have been fairly well distributed from east to west along the ranges.

Counts of both moose ($p < 0.001$) and white-tailed deer ($p < 0.001$) were significantly related to the methods used to conduct aerial surveys. For moose, use of the polygon method resulted in a 9.0 % ($p = 0.465$) higher predicted moose count in relation to the grand mean (the mean of all the sample means) and holding all other variables constant (Table 2.2). The quadrat method resulted in a lower predicted moose count when flown by either fixed-wing or rotary aircraft by 21.3 % ($p = 0.030$) and 27.0 % ($p < 0.001$) respectively. The transect method flown by fixed-wing aircraft resulted in a 26.6 % ($p < 0.001$) lower predicted moose count. However, the transect method flown by rotary aircraft resulted in a 27.9 % ($p = 0.001$) higher predicted moose count. The directed method flown by fixed-wing aircraft resulted in a 6.0 % ($p = 0.466$) lower predicted moose count and the directed method flown by rotary aircraft resulted in an 80.9 % ($p < 0.001$) higher predicted moose count.

For white-tailed deer, in relation to the grand mean and holding all other variables constant, use of the polygon method resulted in an 104.6 % ($p = 0.001$) higher predicted white-tailed deer count (Table 2.2). The transect method using fixed-wing aircraft resulted in a 24.0 % ($p = 0.060$) lower predicted white-tailed deer count. However, using rotary aircraft, the transect method resulted in a 39.6 % ($p = 0.013$) higher predicted white-tailed deer count. The quadrat method using fixed-wing aircraft resulted in an 82.2 % ($p < 0.001$) lower predicted white-tailed

deer count, while when using rotary aircraft resulted in a 20.3 % ($p=0.258$) higher predicted white-tailed deer count. The directed method using fixed-wing aircraft resulted in a 13.6 % ($p=0.583$) lower predicted white-tailed deer count and in a large contrast, using rotary aircraft resulted in a 148.9 % ($p<0.001$) higher predicted white-tailed deer count.

Analysis of Ungulate Counts and Distribution

Moose counts were significantly related to the quadratic of township ($p<0.001$) and the interaction between range and year ($p<0.001$) (Table 2.3). As well, moose counts were significantly related to area surveyed ($p<0.001$), mean township ($p<0.001$) and survey method ($p<0.001$). Mean range was the only variable removed from the model. For the three-dimensional graphs, the model used in considering the relationship between moose counts, year and township was:

$$\text{Moose Counts} = \text{EXP} (\text{Area sampled} + \text{Mean Township} + \text{Year} + \text{Range} + \text{Year*Range} + \text{Township} + \text{Township}^2 + \text{Method})$$

$$\text{Moose counts} = \text{EXP} [(0.0755*9.6) + (-0.0248*80) + (-0.0861*\text{Year}) + (0.0059*12) + (0.0019*125.4) + (0.1805*\text{Township}) + (-0.0011*\text{Township}^2) + (-0.3099*1)]$$

The model used in considering the relationship between moose counts, year and range was:

$$\text{Moose Counts} = \text{EXP} (\text{Area sampled} + \text{Mean Township} + \text{Year} + \text{Range} + \text{Year*Range} + \text{Township} + \text{Township}^2 + \text{Method})$$

$$\text{Moose counts} = \text{EXP} [(0.0755*9.6) + (-0.0248*80) + (-0.0861*\text{Year}) + (0.0059*\text{Range}) + (0.0019*\text{Year*Range}) + (0.1805*80) + (-0.0011*6400) + (-0.3099*1)]$$

Transect flights using fixed-wing aircraft was the aerial survey method selected for creating the graphs, as this was the most prominent method in the dataset.

Three-dimensional graphs of predicted moose counts indicate that moose have declined across all townships in the study area since 1969, with up to seven times fewer moose predicted in townships 70 to 90 in more recent years (Figure 2.9). Prior to the early 1980s moose counts were lower in the far south and north townships than in the mid-range townships. Since the early 1980s, moose, on average, have been evenly distributed across the townships of northeastern

Alberta at low counts. Furthermore, moose counts were lower across the study area from east to west in 2001 than in 1969, with three times fewer moose in the western ranges and five times fewer moose in the eastern ranges of the study area (Figure 2.10). As well, moose counts have declined more rapidly in the eastern portion of the study area. Though moose counts have declined across the northeastern region, moose distribution has remained unchanged, as can be seen by presence-absence maps from 1969 to 1984 and 1985 to 2001 (Figure 2.11 and Figure 2.12). Despite having a statistical model that is highly significant, the fit of the negative binomial model to these data is poor given the evidence of heteroscedasticity and non-normality in the residuals (Figure 2.13 and Figure 2.14).

White-tailed deer counts were significantly related to the interaction of township and year² ($p < 0.001$) (Table 2.4). As well, white-tailed deer counts were significantly related to area surveyed ($p < 0.001$) and survey method ($p < 0.001$). Range, mean range and mean township were all removed from the model. The model used in considering the relationship between white-tailed deer counts and township was:

$$\text{Deer Counts} = \text{EXP} (\text{Area sampled} + \text{Township} + \text{Year} + \text{Year}^2 + \text{Township} * \text{Year} + \text{Township} * \text{Year}^2 + \text{Method})$$

$$\text{Deer counts} = \text{EXP} [(0.0886 * 9.6) + (-0.3316 * 80) + (-1.2799 * \text{Year}) + (0.0398 * \text{Year}^2) + (0.0234 * \text{Township} * \text{Year}) + (-0.0007 * \text{Township} * \text{Year}^2) + (-0.2742 * 1)]$$

The three-dimensional graph of white-tailed deer indicates that on average the counts of this species were four times higher in 2001 than approximately 15 years earlier (Figure 2.15). However, in the area north of township 60, white-tailed deer have remained at low levels since 1969. Prior to the early 1980s white-tailed deer were relatively evenly distributed at low counts across the townships of northeastern Alberta. As well, white-tailed deer distribution has expanded northwards since 1969. This is clearly seen from presence-absence maps from 1969 to 1984 and 1985 to 2001 (Figure 2.16 and Figure 2.17). In considering the fit of the white-tailed deer count model, unexplained trends in the data also remain (Figure 2.18). As well, a histogram of the

Anscombe residuals indicates that there is a strong skew in the residual data, also suggesting poor model fit (Figure 2.19).

Discussion

Survey method in my analysis significantly affected ungulate counts. In both the moose and white-tailed deer models, rotary aircraft resulted in higher counts than fixed-wing aircraft for all methods, with the exception of fixed-wing quadrat flights for moose. This supports previous studies that found observers in fixed-wing aircraft saw only 29 % of moose that were counted from the helicopter (Crete et al. 1986). As well, the fact that directed flights resulted in the highest counts of both ungulate species is appropriate given that these flights seek out concentrations of animals. However, the lower counts of moose predicted by the polygon method in comparison to transect surveys was unexpected given that past studies have found that intensive searches with a circling flight pattern provide a higher detection rate than transect flights (Peterson and Page 1993). The reason for the discrepancy between previous studies and my results may be that with the Gasaway method, managers survey areas of low concentrations of ungulates in order to capture the variability of the population, which subsequently lowers mean counts (Gasaway et al. 1986). Likewise, quadrat surveys predicting lower counts than transect surveys for both ungulate species, seemed contrary to previous studies (Peterson and Page 1993, Pojar et al. 1994). The reason for the discrepancy between previous studies and my results may be that with quadrats, which typically survey small areas (2.6km²), observers may have a greater chance of not observing any ungulates.

The declines in moose counts in northeastern Alberta from 1969 to 2001 that I show are consistent with the decline of moose populations in the entire province of Alberta since 1977 (Stelfox and Stelfox 1993b). Stelfox and Stelfox (1993b) identified increasing wolf populations, recreational hunting, the advent of all-terrain vehicles and tick infestations as factors leading to the decline of moose. However, harvest and effort surveys conducted by Alberta Sustainable

Resource Development have indicated a decline in the number of moose harvested since 1988, likely as a result of fewer moose hunters (ASRD 1985-2000). An additional set of factors that may be contributing to the decline are those resulting from human landuse, as moose are generally considered susceptible to human disturbance pressures (Nietfeld et al. 1985). Regardless, the declining moose population may be a concern for wildlife managers, given the importance of moose as a game species and in influencing ecosystem dynamics.

The distribution of moose I observed, with lower counts in the far northern and southern regions of the northeast, may be due to the lack of suitable habitat in the agricultural zone to the south and in the Canadian Shield to the north. These areas have been identified as containing secondary or poor habitat for moose (Stelfox and Stelfox 1993a). However, the more rapid decline of moose abundance in the eastern portion of the study area was an unexpected result. A possible explanation for this could be that the human activity level in the eastern portion of my study area is, in some areas, more intense than the western region. The city of Fort McMurray lies in the eastern portion of the study area. Located near here, oil sands developments have been active since 1968 (Chastko 2004). Further consideration of the mechanisms linked to this trend is necessary in order to determine potential causes.

I found that white-tailed deer counts were higher in 1969 than 2001 in the southern portion of my study area. This coincides with the increased abundance of white-tailed deer documented across North America (Augustine and de Calesta 2003, Van Deelen 1996). Higher counts of white-tailed deer were apparent in my study, despite more deer having been harvested by hunters since 1985, indicating that management practices are not limiting the population (ASRD 1985-2000). In addition to greater counts of deer, I also found that they have expanded northward. My findings are supported by other studies, which have noted that the white-tailed deer range may be expanding into northern areas with the expansion of agriculture and industrial developments (AEP 1995, Bayne et al. 2004). Both forested land conversion and industrial

developments have increased in northern Alberta since 1969 (Schneider 2002). Therefore, the higher counts and range expansion of this species is understandable given that agricultural and industrial developments may create high quality habitat for white-tailed deer (AEP 1995).

While the popularity of white-tailed deer as a game species makes their higher counts and expanded distribution favourable to the hunting community, potential negative implications exist as well. The expansion of white-tailed deer may influence predator-prey dynamics present in the boreal ecosystem by offering an additional prey source to predators, specifically wolves (*Canis lupus*) (Gunson et al. 1993). This increased prey availability could lead to higher wolf populations, resulting in increased pressures on sensitive prey species like the woodland caribou (*Rangifer tarandus*). If white-tailed deer counts continues to rise further north, they will populate the southernmost woodland caribou ranges, which include the Cold Lake Air Weapons Range population, the east side of the Athabasca River population and the west side of the Athabasca river population (McLoughlin et al. 2004). An additional negative implication of higher white-tailed deer counts is that it will likely result in more reports of depredation on agricultural crops. In Alberta, reports of white-tailed and mule deer (*Odocoileus hemionus*) depredation on crops accounted for 68 % of complaints between 1982 and 1991 (Wishart et al. 1993). White-tailed deer have also been associated with changes to forest structure and composition as a result of heavy browsing (Van Deelen et al. 1996). Therefore, browsing damage could influence the forestry sector. As well, higher white-tailed deer counts may contribute to the spread of disease and parasites, as with increasing populations, the likelihood of encountering infected deer increases. For example, white-tailed deer have been identified as potential vectors for the transmission of the parasite *Neospora caninum* (Gondim et al. 2004) and the transmission of the bacterium *Mycobacterium bovis* (Palmer et al. 2004).

This study identified changes in white-tailed deer and moose counts and distribution in northeastern Alberta over 32 years. However, residual analyses indicate that the fit of the negative

binomial model was poor for both moose and white-tailed deer models. The skewed residuals may have been due to an excess of zeros and may be rectified by modeling with a zero-inflated count model. Zero-inflated models are typically used when there is a higher incidence of zeros than would be expected by the count model distribution (Ridout et al. 2001). As well, both residual plots for the moose and white-tailed deer count models indicated that there are still unexplained trends in the residual data. These unexplained trends may be partially explained by factors that are possibly contributing to the observed population changes. In particular, the relationship between cumulative impacts and these ungulates is of interest, given the recent and rapid development of disturbances in the northeast region of Alberta. This is the topic for Chapter 3 of my thesis.

Literature Cited

- Alberta Environmental Protection (AEP). 1995. Management Plan for White-tailed Deer in Alberta. Alberta Environmental Protection, Edmonton, Alberta, Canada. 142 pp.
- Alberta Environmental Protection (AEP). 1998. The Boreal Forest Natural Region of Alberta. Alberta Environmental Protection, Edmonton, Alberta, Canada. 313 pp.
- Alberta Sustainable Resource Development (ASRD). 1985-2000. Harvest and Effort by Resident Hunters. Alberta Sustainable Resource Development, Edmonton, Alberta, Canada.
- Augustine, D.J. and D. de Calesta. 2003. Defining deer overabundance and threats to forest communities: From individual plants to landscape structure. *Ecoscience*. 10: 472-486.
- Bayne, E., S. Boutin and R. Moses. 2004. Are boreal forest mammals good indicators of cumulative effects? Sustainable Forest Management Network, Edmonton, Alberta, Canada. 43 pp.
- Chastko, P.A. 2004. Developing Alberta's oil sands: from Karl Clark to Kyoto. University of Calgary Press, Calgary, Alberta, Canada. 320 pp.

- Cohen, B.A., R.D. Mitra, J.D. Hughes and G.M. Church. 2000. A computational analysis of whole-genome expression data reveals chromosomal domains of gene expression. *Nature America*. 26: 183-186.
- Crete, M., L.P. Rivest, H. Jolicoeur, J.M. Brassard and F. Messier. 1986. Predicting and correcting helicopter counts of moose with observations made from fixed-wing aircraft in southern Quebec. *Journal of Applied Ecology*. 23: 751-761.
- Gasaway, W.C, S.D. Dubois, D.J. Reed and S.J. Harbo. 1986. Estimating moose population parameters from aerial surveys. University of Alaska, Fairbanks, Alaska. 108 pp.
- Gondim, L.F.P., M.M. McAllister, N.E. Mateus-Pinilla and W.C. Pitt. 2004. Transmission of *Neospora caninum* between wild and domestic animals. *Journal of Parasitology*. 90: 1361-1365.
- Gunson, J.R., M. Jalkotzy, L.N. Carbyn and L.D. Roy. 1993. Predation. Pp. 69-80 in Stelfox, J.B., ed. *Hoofed Mammals of Alberta*. Lone Pine Publishing, Edmonton, Alberta, Canada. 241 pp.
- Hardin, J. and J. Hilbe. 2001. *Generalized Linear Models and Extensions*. Stata Press, College Station, Texas, U.S.A. 245 pp.
- Hosmer, D.W. and S. Lemeshow. 2000. *Applied Logistic Regression*. John Wiley and Sons, Inc., New York, New York, U.S.A. 373 pp.
- Krebs, C.J. 2001. *Ecology*. Benjamin Cummings, San Francisco, California, U.S.A. 695 pp.
- Lawlor, T.E. 2003. Faunal composition and distribution of mammals in western coniferous forests. Pp. 41-80 in Zabel, C.J. and R.G. Anthony, eds. *Mammal Community Dynamics: Management and Conservation in the Coniferous Forests of Western North America*. Cambridge University Press, Cambridge, U.K. 709 pp.
- McLoughlin, P.D., D. Paetkau, M. Duda and S. Boutin. 2004. Genetic diversity and relatedness of boreal caribou populations in western Canada. *Biological Conservation*. 118: 593-598.

- Moen, R., Y. Cohen and J. Pastor. 1998. Linking moose population and plant growth models with a moose energetics model. *Ecosystems*. 1: 52-63.
- Nelder, J.A. 1990. Nearly Parallel Lines in Residual Plots. *The American Statistician*. 44: 221-222.
- Nietfeld, M., J. Wilk, K. Woolnough, and B Hoskin. 1985. Wildlife habitat requirement summaries for selected wildlife species in Alberta. Alberta Energy and Natural Resources, Fish and Wildlife Division, Wildlife Resource Inventory Unit, Canada. 260 pp.
- Palmer, M.V., W.R. Waters and D.L. Whipple. 2004. Investigation of *Mycobacterium bovis* from deer to cattle through indirect contact. *American Journal of Veterinary Research*. 65: 1483-1489.
- Pastor, J., B. Dewey, R. Moen, D.J. Mladenoff, M. White and Y. Cohen. 1998. Spatial patterns in the moose-forest-soil ecosystem on Isle Royale, Michigan, U.S.A. *Ecological Applications*. 8: 411-424.
- Peterson, R.O. and R.E. Page. 1993. Detection of moose in midwinter from fixed-wing aircraft over dense forest cover. *Wildlife Society Bulletin*. 21: 80-86.
- Pojar, T.M., D.C. Bowden and R.B. Gill. 1994. Aerial counting experiments to estimate pronghorn density and herd structure. *Journal of Wildlife Management*. 59: 117-128.
- Ridout, M., J. Hinde and C.G.B. Demetrio. 2001. A score test for testing a zero-inflated poisson regression model against zero-inflated negative binomial alternatives. *Biometrics*. 57: 219-223.
- Schneider, R.R. 2002. Alternative Futures: Alberta's Boreal Forest at the Crossroads. The Federation of Alberta Naturalists, Edmonton, Alberta, Canada. 152 pp.
- Seagle, S.W. 2003. Can ungulates foraging in a multiple-use landscape alter forest nitrogen budgets? *Oikos*. 103: 230-234.

- Seip, D.R. 1995. Introduction to wolf-prey interactions. Pp. 179-186 in Carbyn, L.N., S.H. Fritts and D.R. Seip, eds. *Ecology and Conservation of Wolves in a Changing World*. Canadian Circumpolar Institute, Occasional Publication No.35. 642 pp.
- Smith, A.R. 2004. 30th and 31st Annual Saskatchewan Christmas Mammal Counts – 2002 and 2003. *Blue Jay*. 62: 140-159.
- StataCorp. 2004. *Intercooled Stata 8.2 for Windows*. StataCorp, Texas, U.S.A.
- Stelfox, J.B. and J.G. Stelfox. 1993a. Distribution. Pp. 45-61 in Stelfox, J.B., ed. *Hoofed Mammals of Alberta*. Lone Pine Publishing, Edmonton, Alberta, Canada. 241 pp.
- Stelfox, J.B. and J.G. Stelfox. 1993b. Population dynamics and reproduction. Pp. 63-68 in Stelfox, J.B., ed. *Hoofed Mammals of Alberta*. Lone Pine Publishing, Edmonton, Alberta, Canada. 241 pp.
- SYSTAT Software Inc. 2001. *SigmaPlot*. SYSTAT Software Inc., Richmond, California, U.S.A.
- Timmerman, H.R. 1974. Moose Inventory Methods: A Review. *Le Naturaliste Canadien*. 101: 615-629.
- Van Deelen, T.R., K.S. Pregitzer and J.B. Haufler. 1996. A comparison of presettlement and present-day forests in two northern Michigan deer yards. *American Midland Naturalist*. 135: 181-194.
- Wishart, W.D., J.G. Stelfox, E.S. Telfer and J.R. Gunson. 1993. Management. Pp. 107-118 in Stelfox, J.B., ed. *Hoofed Mammals of Alberta*. Lone Pine Publishing, Edmonton, Alberta, Canada. 241 pp.

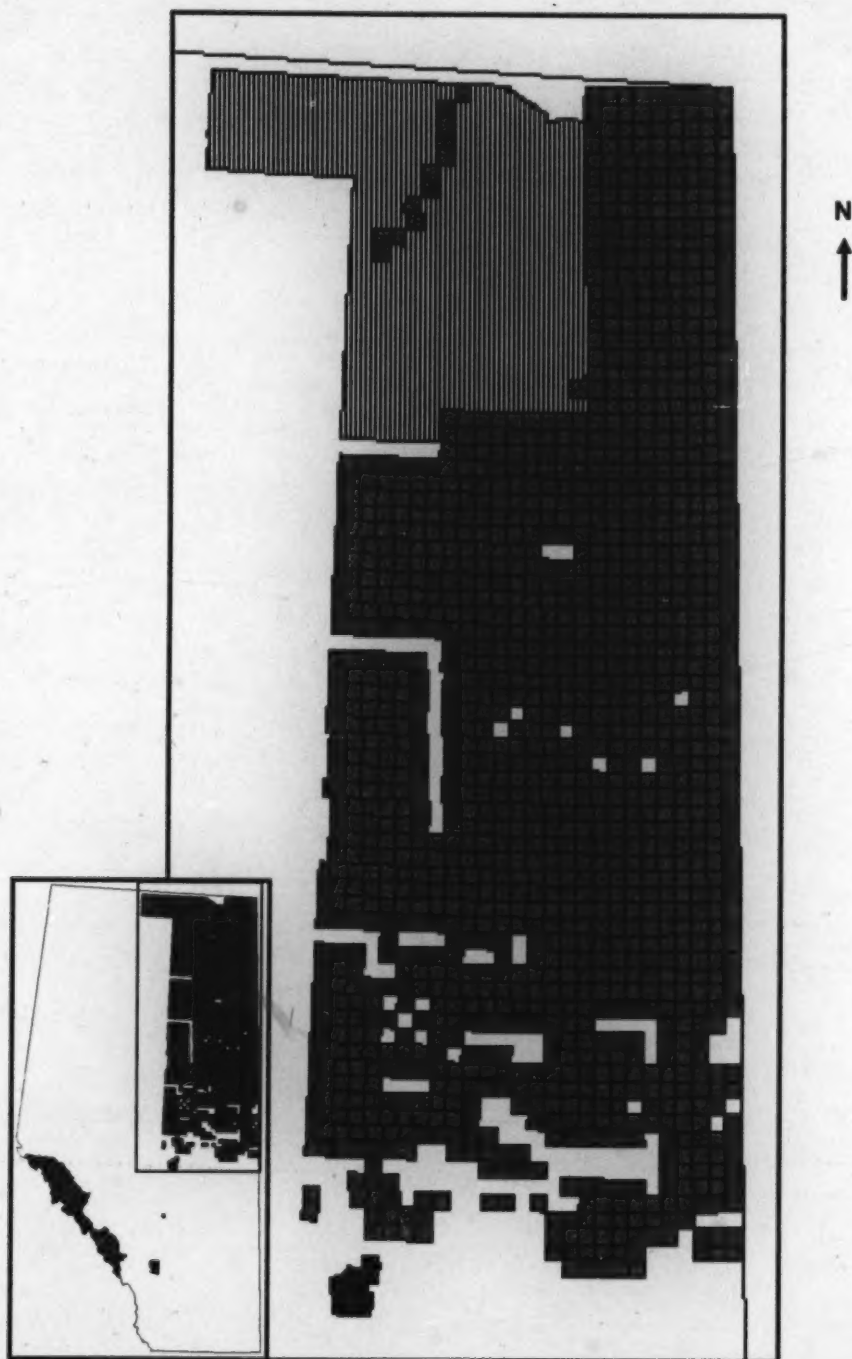


Figure 2.1: Northeastern Alberta study area. Inset shows location in Alberta. Townships surveyed for moose and white-tailed deer by Alberta Sustainable Resource Development from 1969 to 2001 in dark grey. Black areas indicate urban centres and striped areas indicate protected areas.

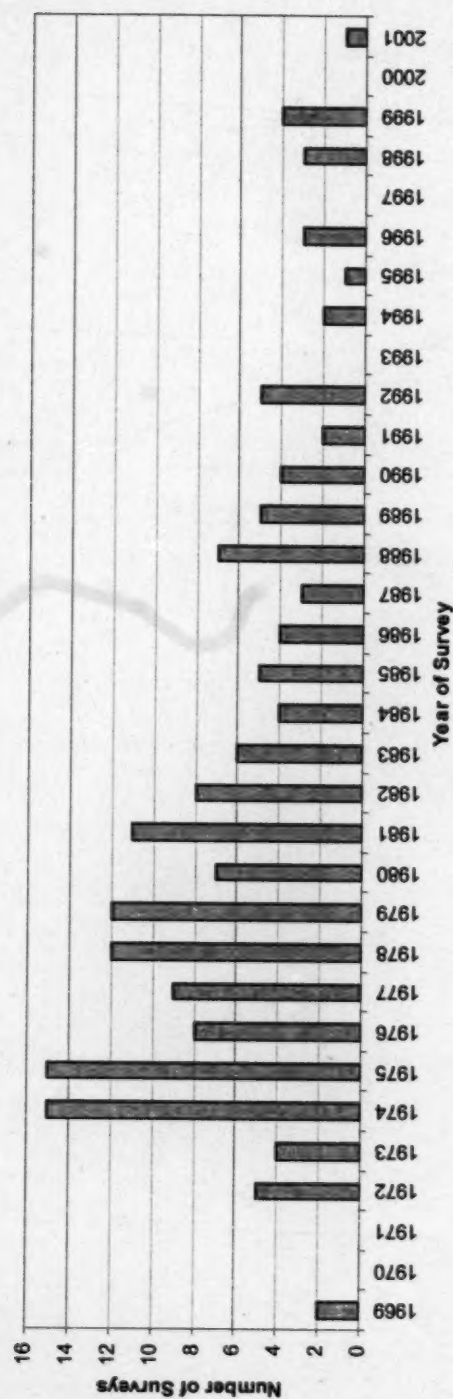


Figure 2.2: Annual number of ungulate surveys in northeastern Alberta. Collected from Alberta Sustainable Resource Development for 1969 to 2001.

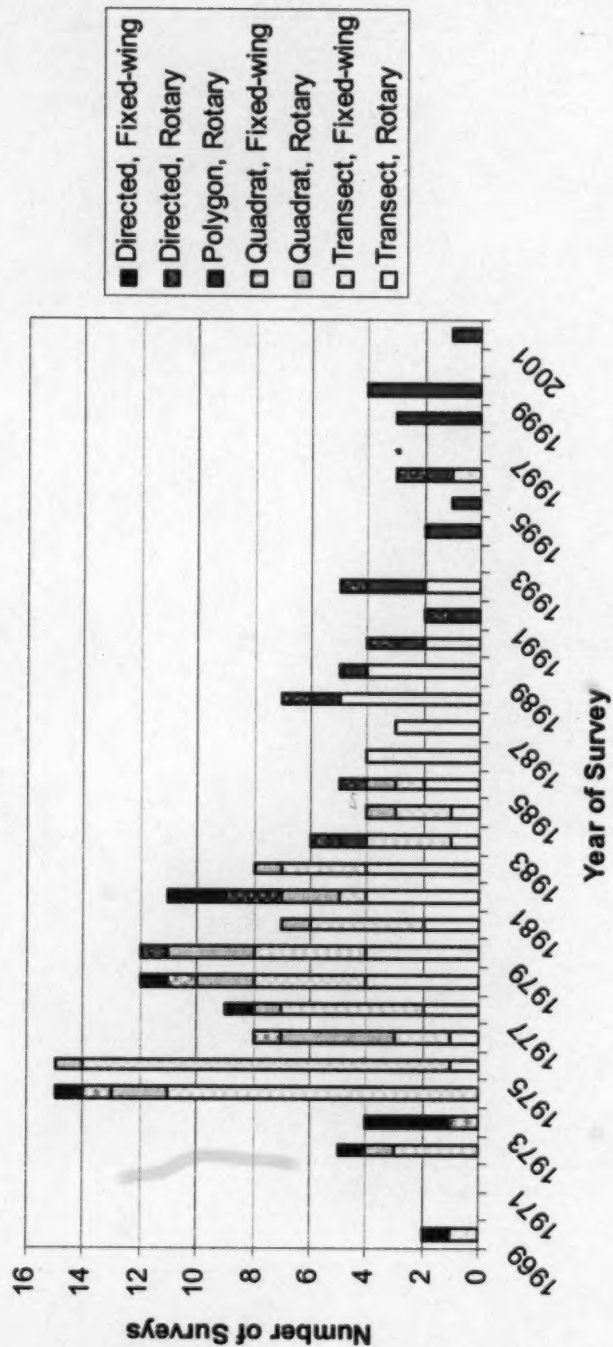


Figure 2.4: Survey method and aircraft types used by Alberta Sustainable Resource Development to conduct aerial ungulate surveys in northeastern Alberta from 1969 to 2001.

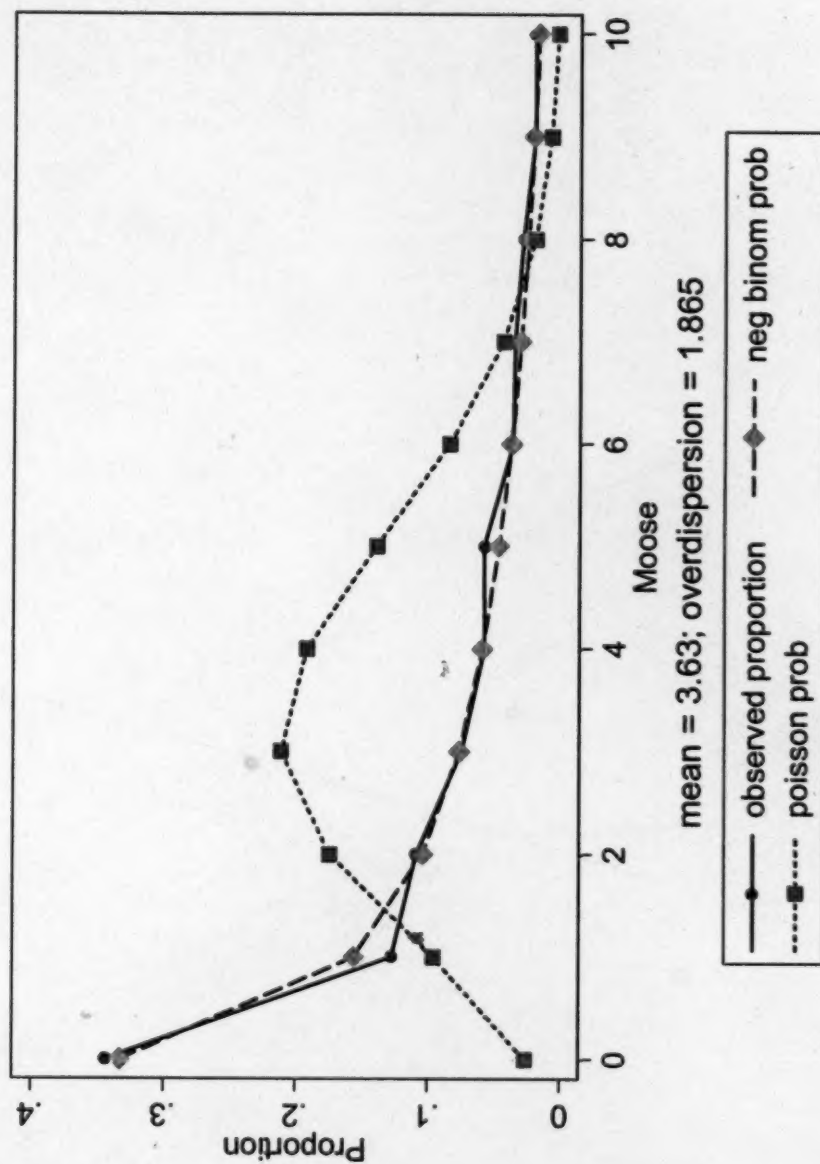


Figure 2.5: Comparison of observed proportions of moose counts from Alberta Sustainable Resource Development ungulate surveys flown in northeastern Alberta (1969-2001) to negative binomial and Poisson distributions.

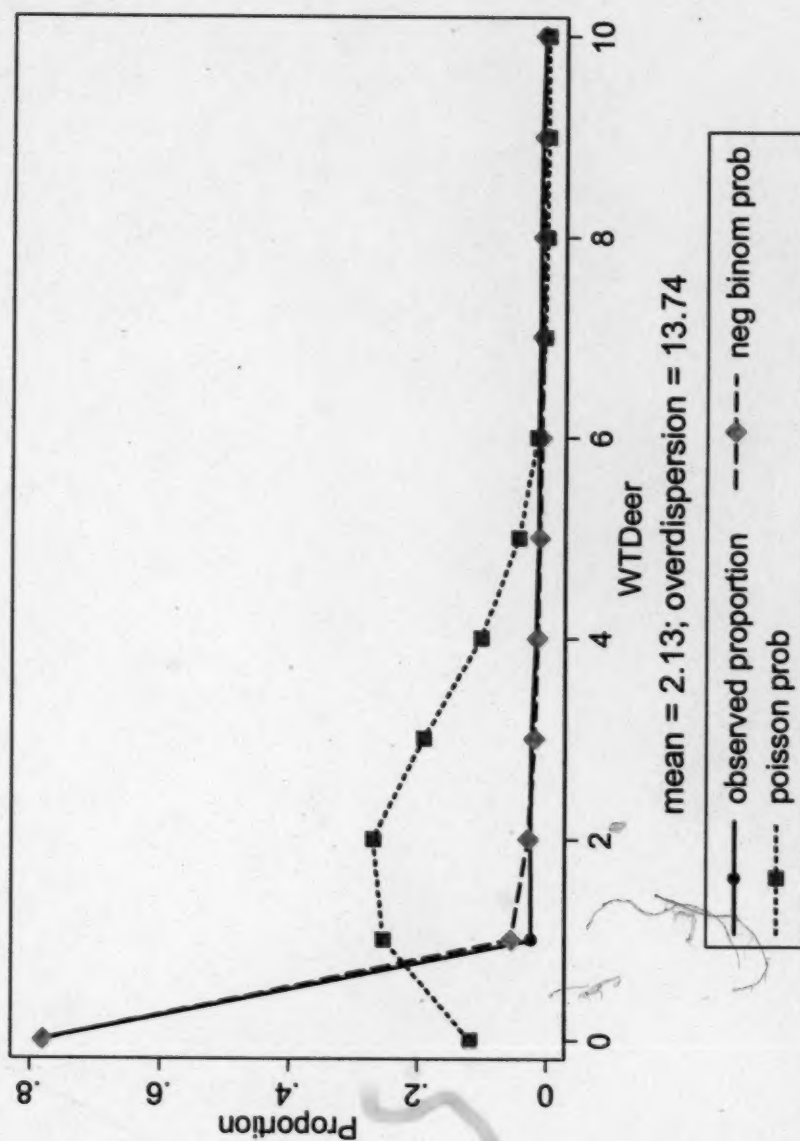


Figure 2.6: Comparison of observed proportions of white-tailed deer counts from Alberta Sustainable Resource Development ungulate surveys flown in northeastern Alberta (1969-2001) to negative binomial and Poisson distributions.

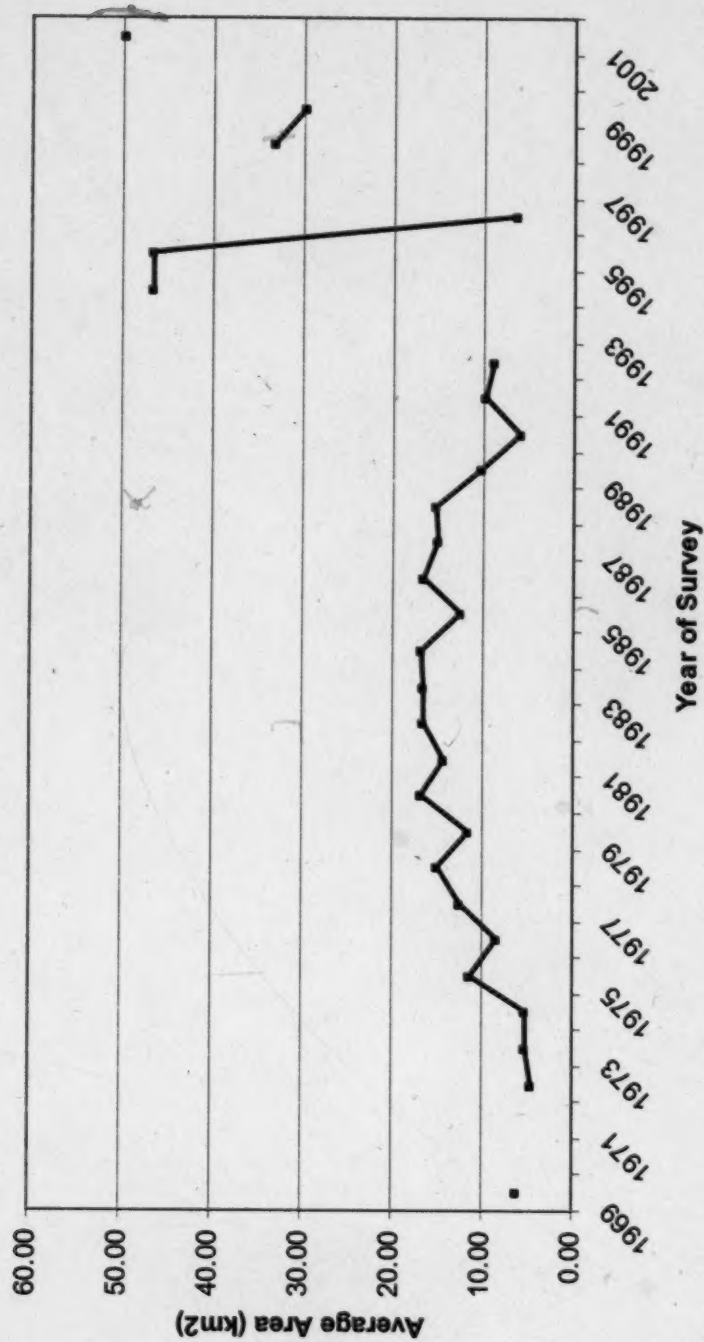


Figure 2.7: Average area surveyed within a township by year of survey for Alberta Sustainable Resource Development ungulate surveys flown in northeastern Alberta from 1969 to 2001.

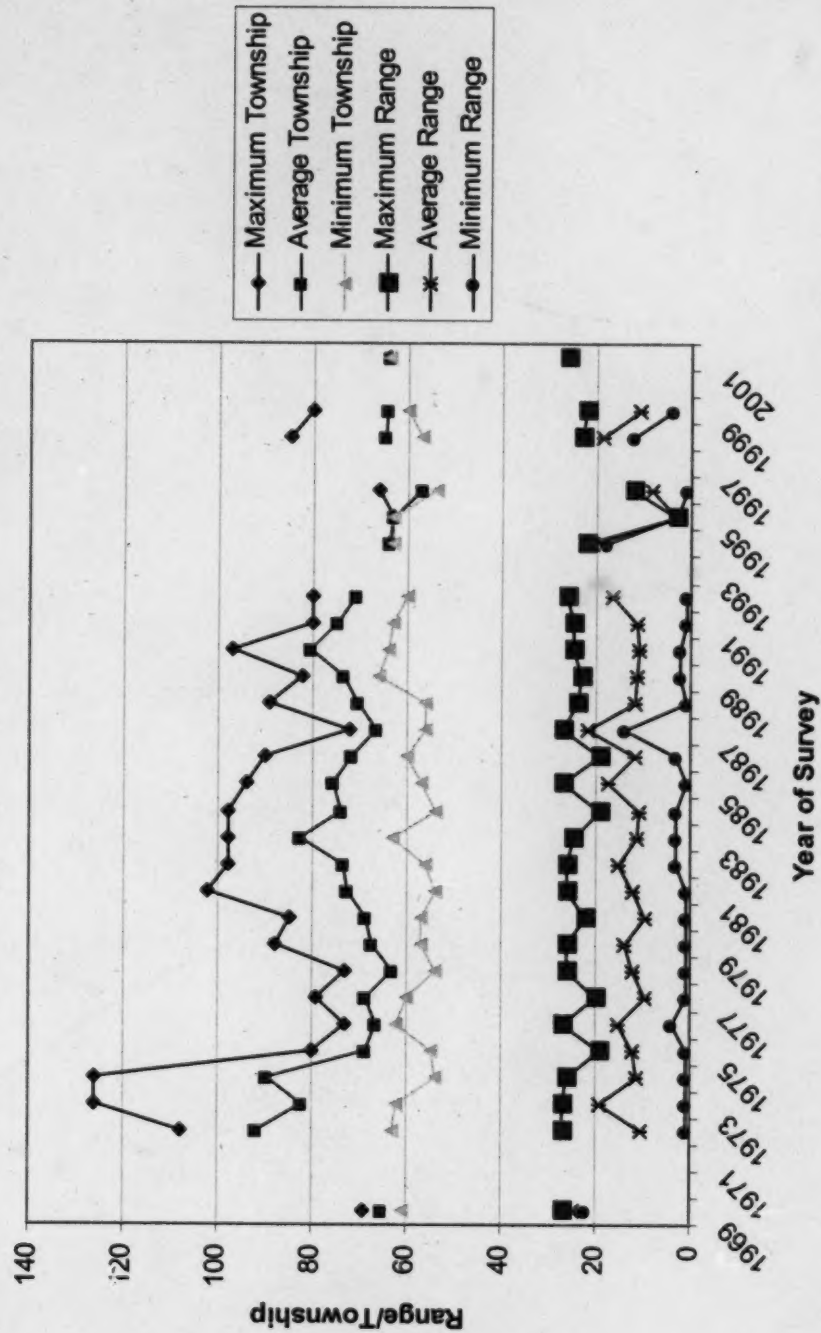


Figure 2.8: Location surveyed (expressed by township and range coordinates) by year of survey for Alberta Sustainable Resource Development ungulate surveys flown in northeastern Alberta from 1969 to 2001.

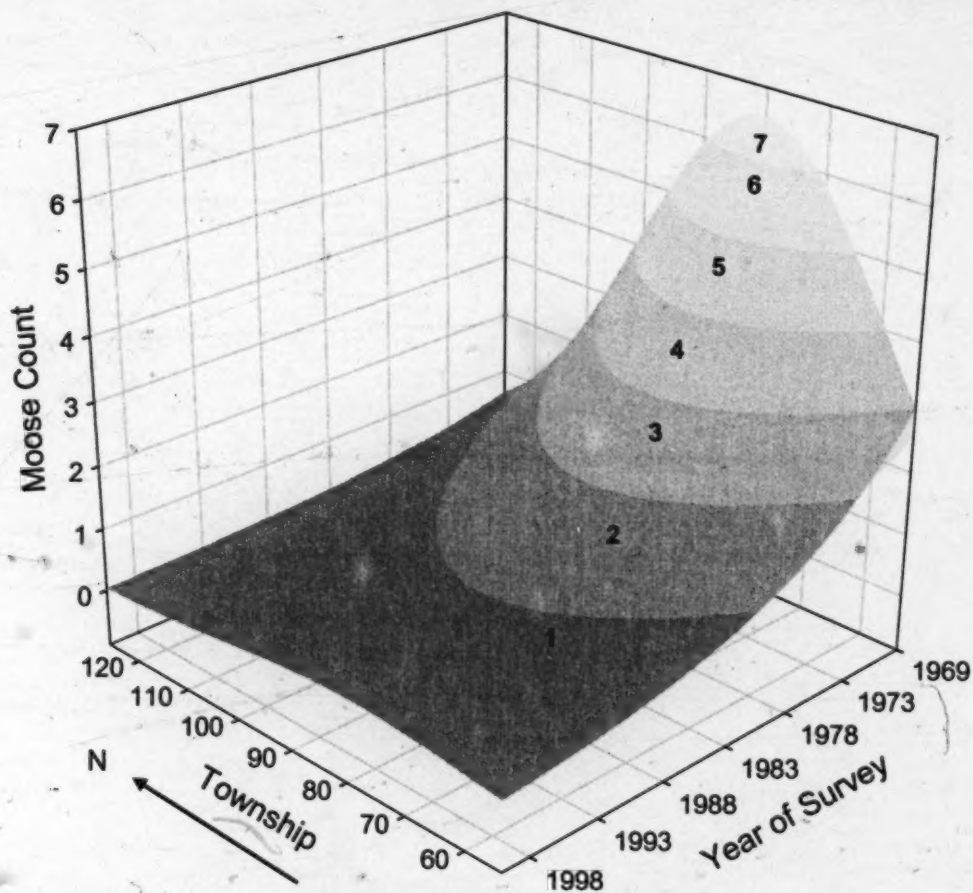


Figure 2.9: Three-dimensional graph of average predicted moose counts in northeastern Alberta by township and year of survey for study period from 1969 to 2001. Higher township numbers indicate a location further north. Township 54 is the most southerly township in the study area at 53.6°N latitude. Township 126 is the most northerly township in the study area at 59.9°N latitude.

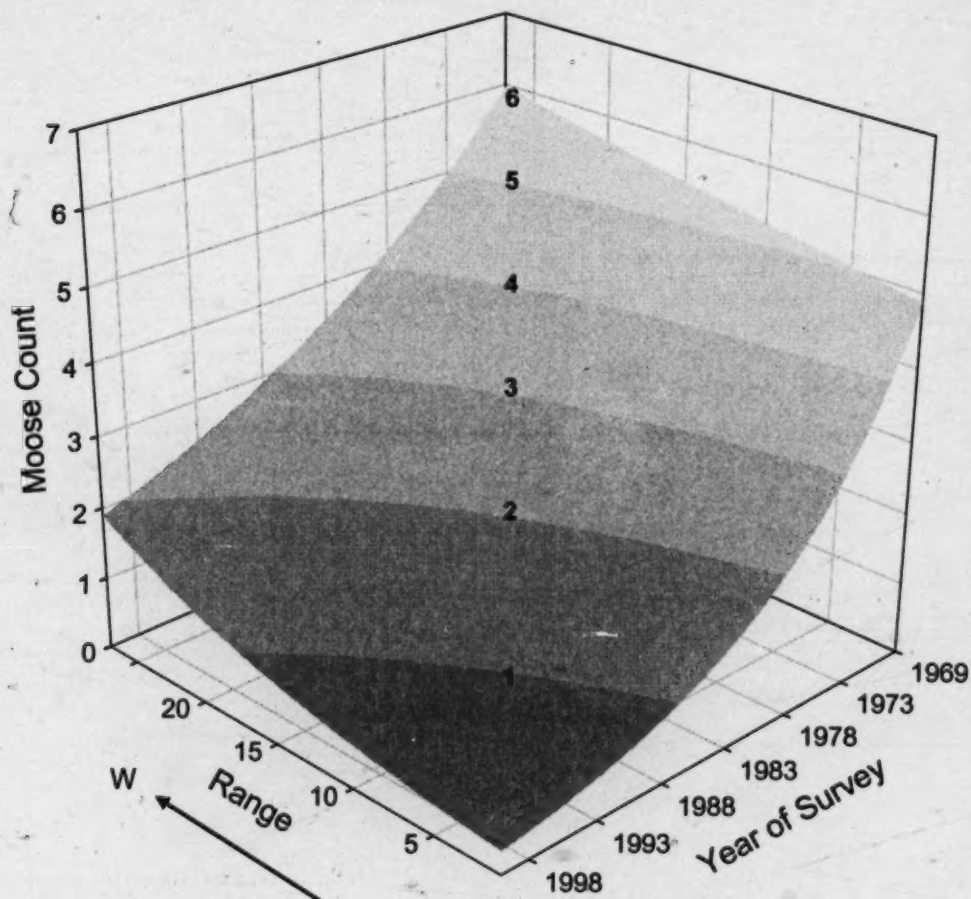


Figure 2.10: Three-dimensional graph of average predicted moose counts in northeastern Alberta by range and year of survey for study period from 1969 to 2001. Higher range numbers indicate a location further west. Range 1 is the most easterly range in the study area at 110.0°W longitude. Range 27 is the most westerly range in the study area at 113.9°W longitude.

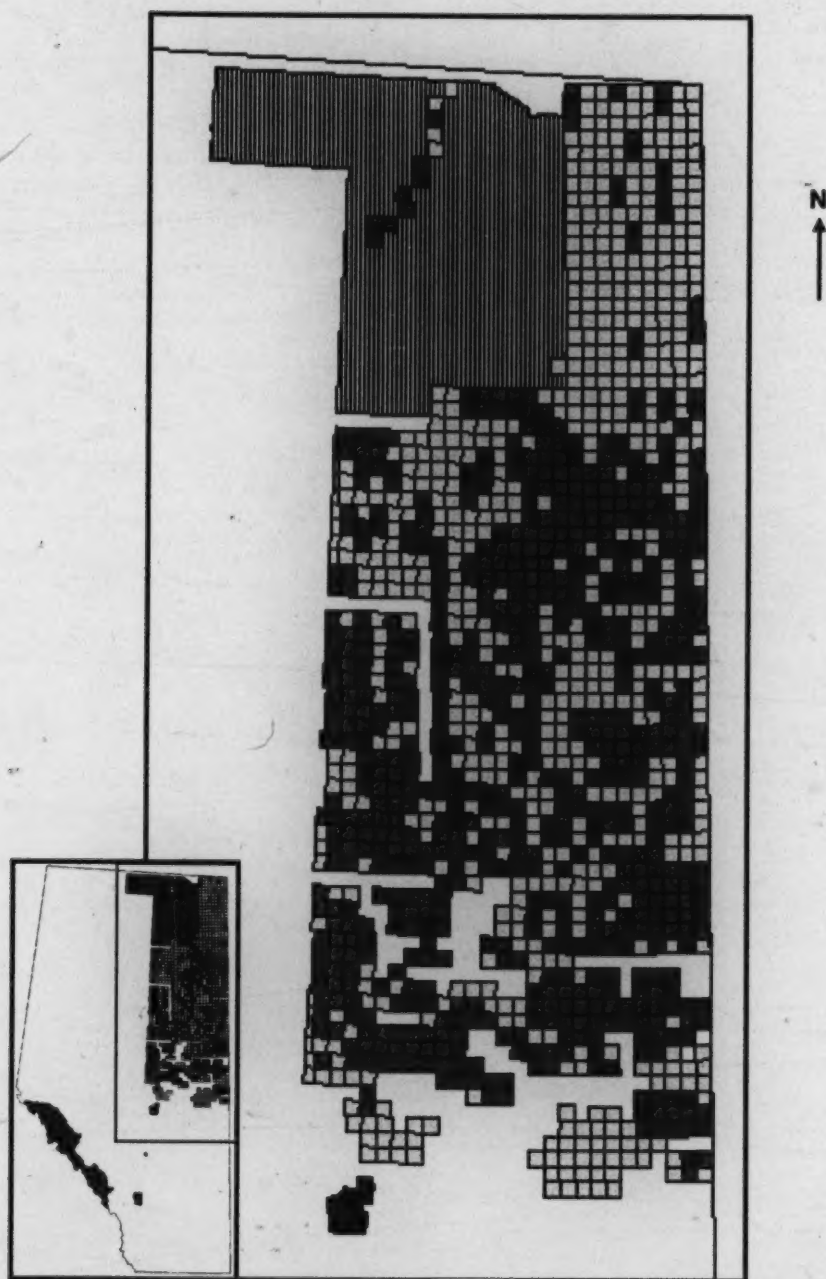


Figure 2.11: Presence-absence map of moose in northeastern Alberta based on surveys conducted by Alberta Sustainable Resource Development from 1969 to 1984. Inset shows location in Alberta. Dark grey indicates townships where moose are present. Light grey indicates townships where moose are absent. Black areas indicate urban centres and striped areas indicate protected areas.

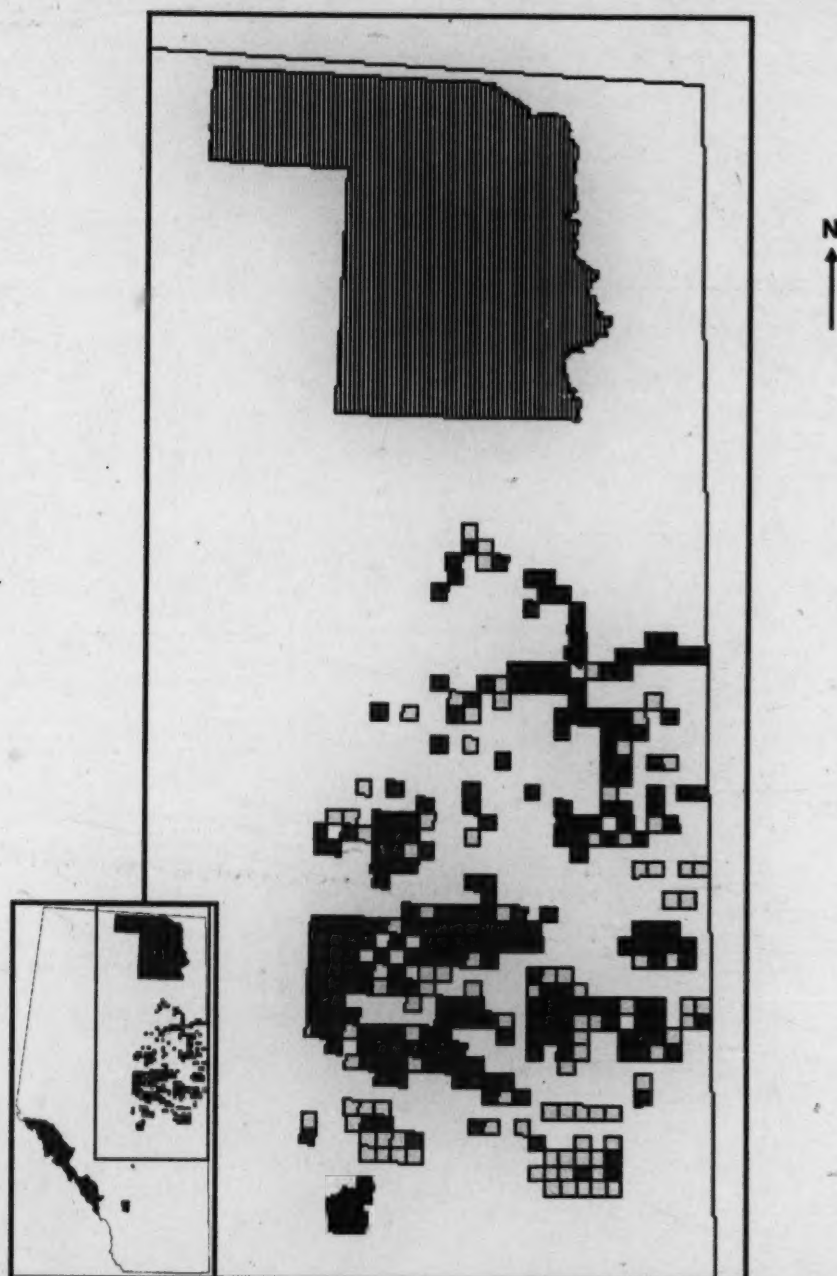


Figure 2.12: Presence-absence map of moose in northeastern Alberta based on surveys conducted by Alberta Sustainable Resource Development from 1985 to 2001. Inset shows location in Alberta. Dark grey indicates townships where moose are present. Light grey indicates townships where moose are absent. Black areas indicate urban centres and striped areas indicate protected areas.

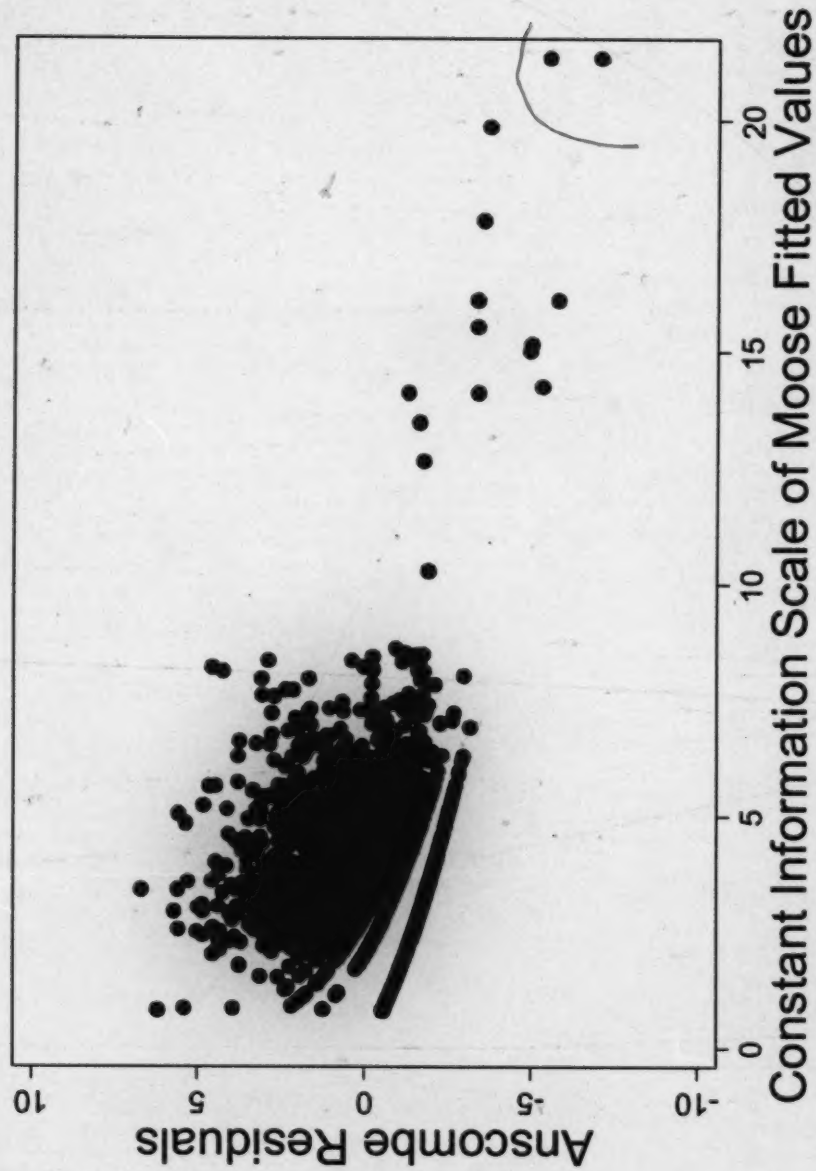


Figure 2.13: Residual plot of constant information scale fitted values of moose counts against Anscombe residual values for the analysis of moose counts within sample sites in northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1969 to 2001.

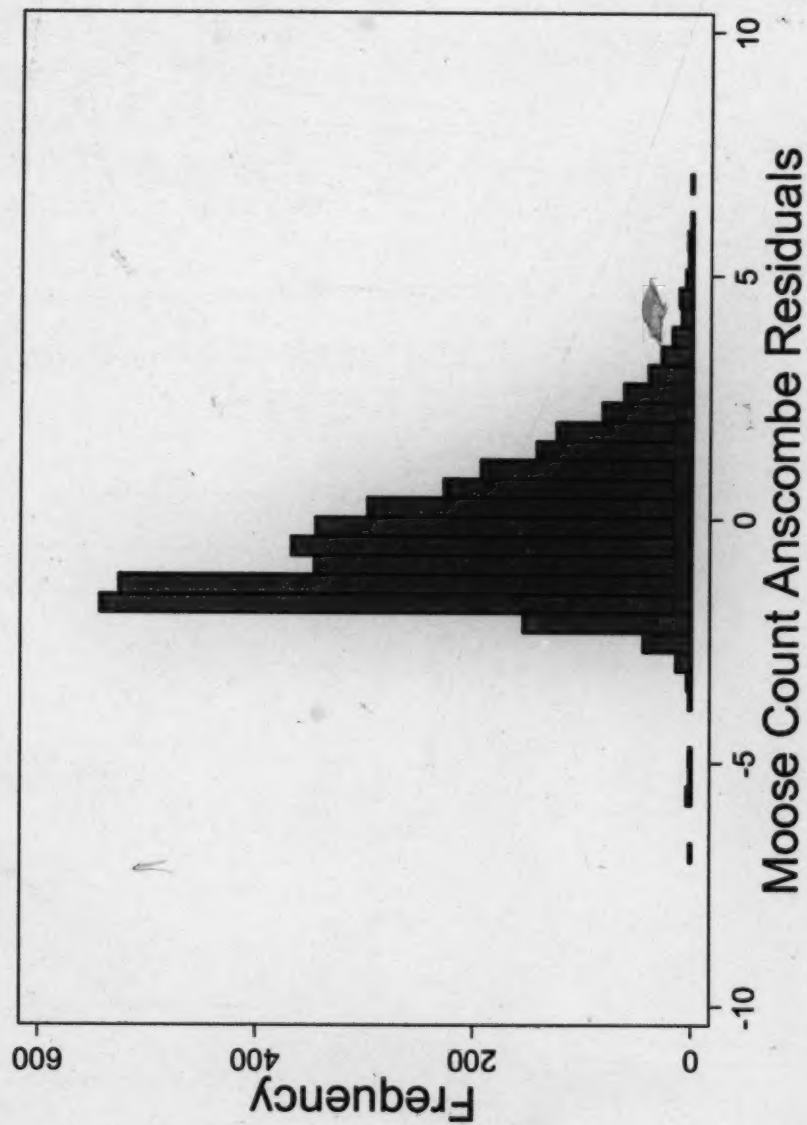


Figure 2.14: Histogram of moose count Anscombe residuals for the analysis of moose counts within sample sites in northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1969 to 2001.

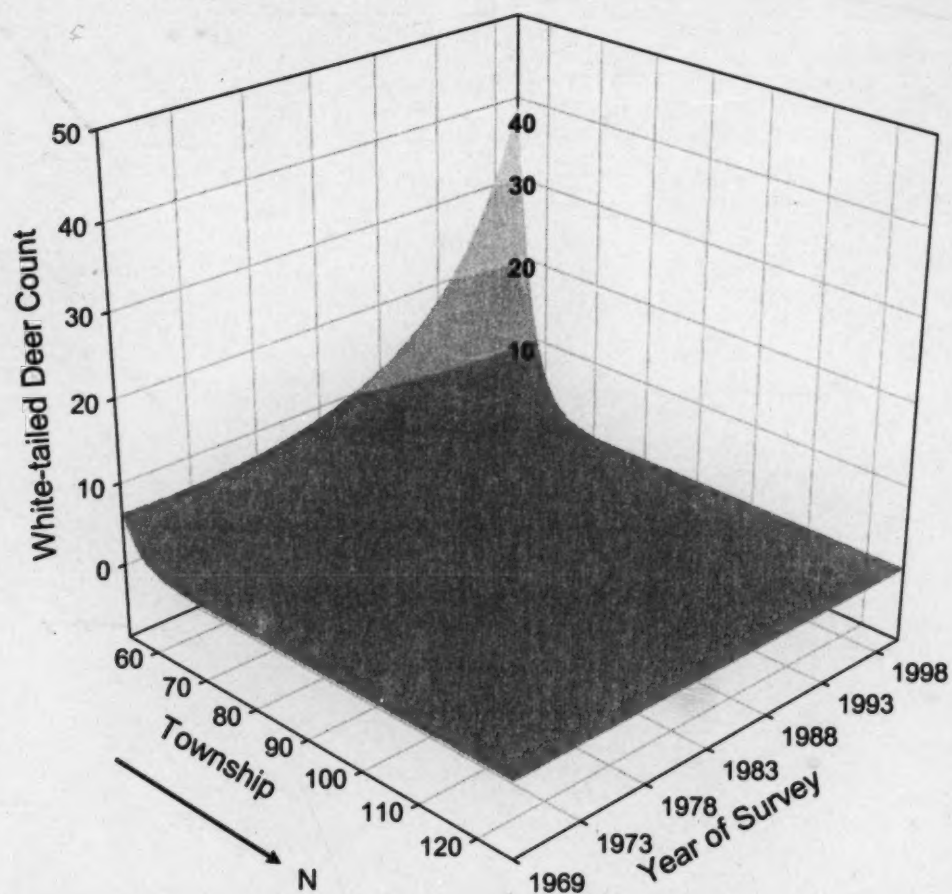


Figure 2.15: Three-dimensional graph of average predicted white-tailed deer in northeastern Alberta counts by township and year of survey for study period from 1969 to 2001. Higher township numbers indicate a location further north. Township 54 is the most southerly township in the study area at 53.6°N latitude. Township 126 is the most northerly township in the study area at 59.9°N latitude. Note that the direction of the axes have changed in relation to previous figures in order to make the visual representation of the trends in the data more clear.

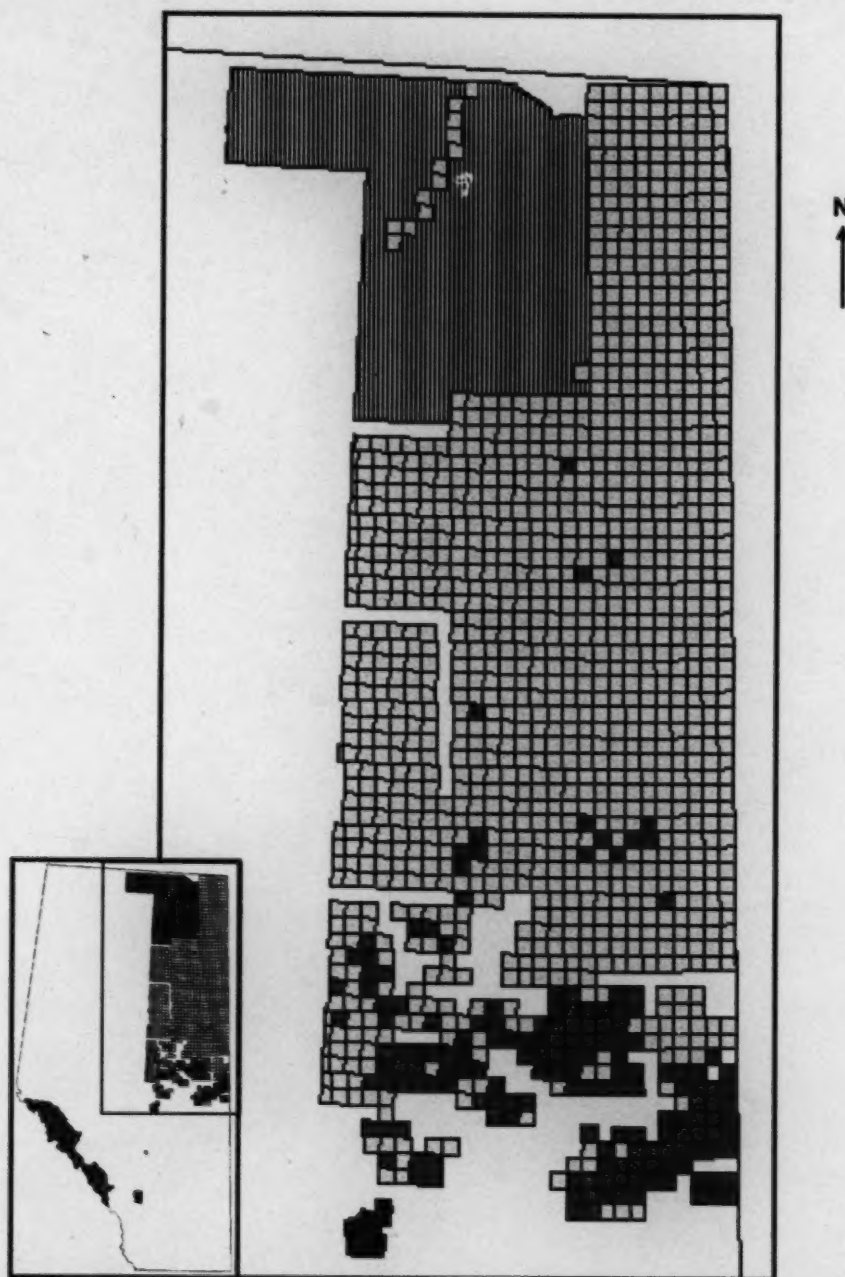


Figure 2.16: Presence-absence map of white-tailed deer in northeastern Alberta based on surveys conducted by Alberta Sustainable Resource Development from 1969 to 1984. Inset shows location in Alberta. Dark grey indicates townships where deer are present. Light grey indicates townships where deer are absent. Black areas indicate urban centres and striped areas indicate protected areas.

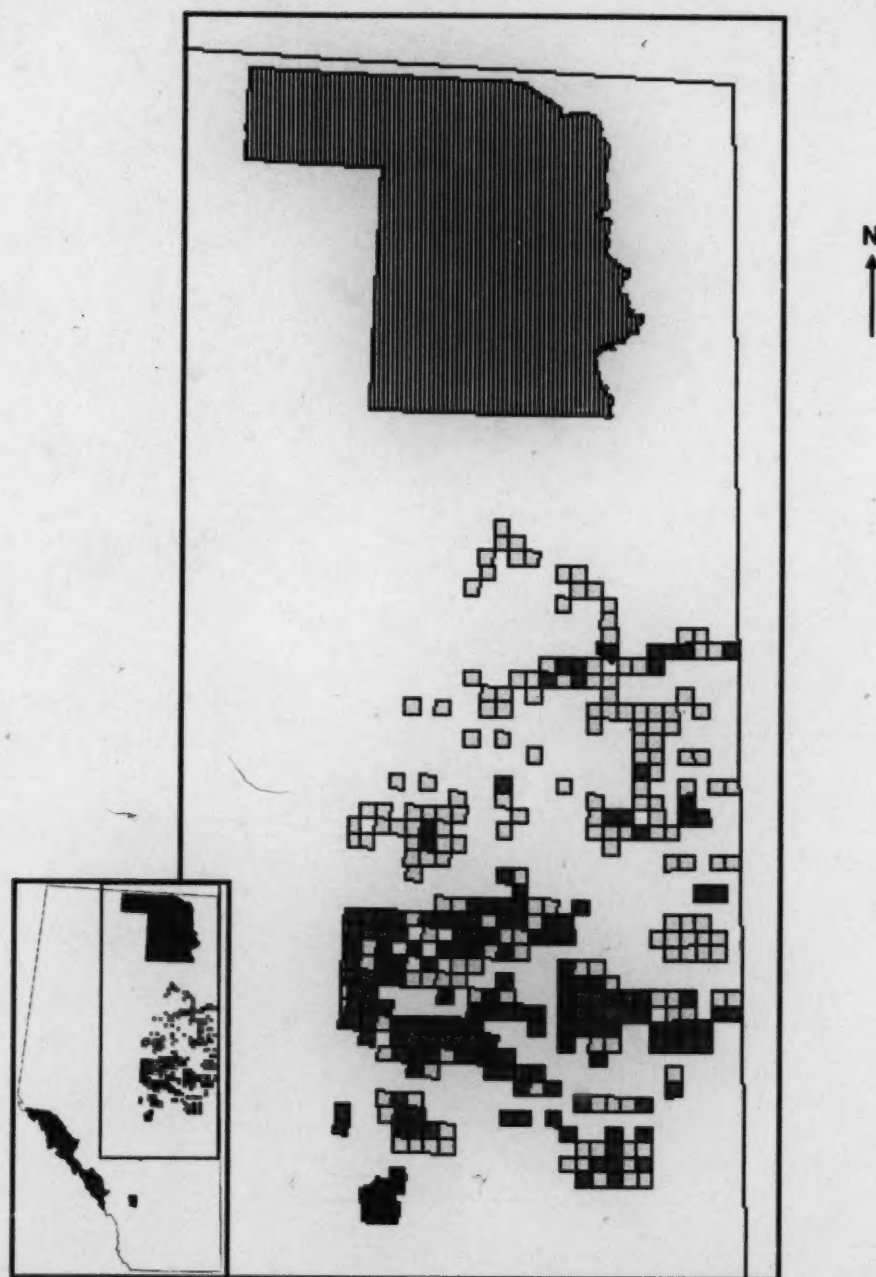


Figure 2.17: Presence-absence map of white-tailed deer in northeastern Alberta based on surveys conducted by Alberta Sustainable Resource Development from 1985 to 2001. Inset shows location in Alberta. Dark grey indicates townships where deer are present. Light grey indicates townships where deer are absent. Black areas indicate urban centres and striped areas indicate protected areas.

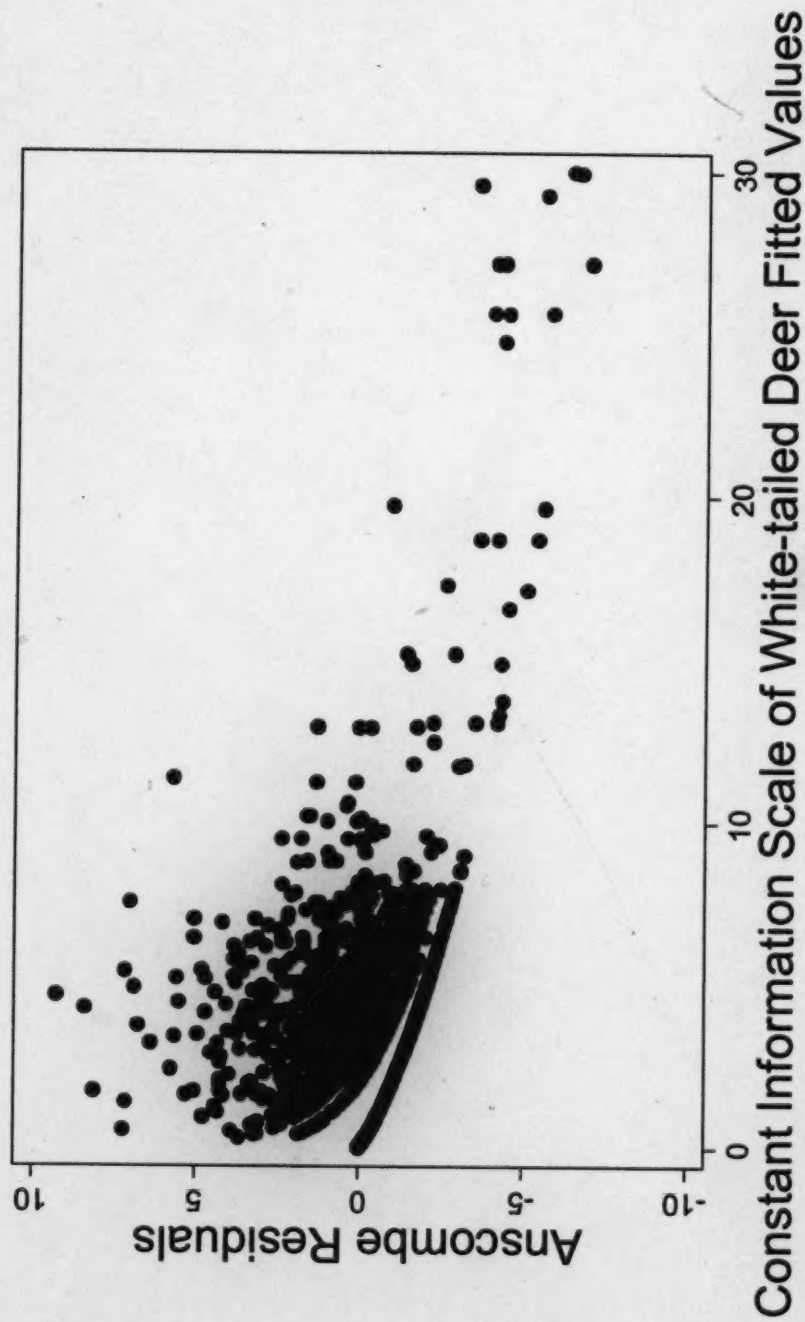


Figure 2.18: Residual plot of constant information scale fitted values of white-tailed deer counts against Anscombe residual values for the analysis of white-tailed deer counts within sample sites in northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1969 to 2001.

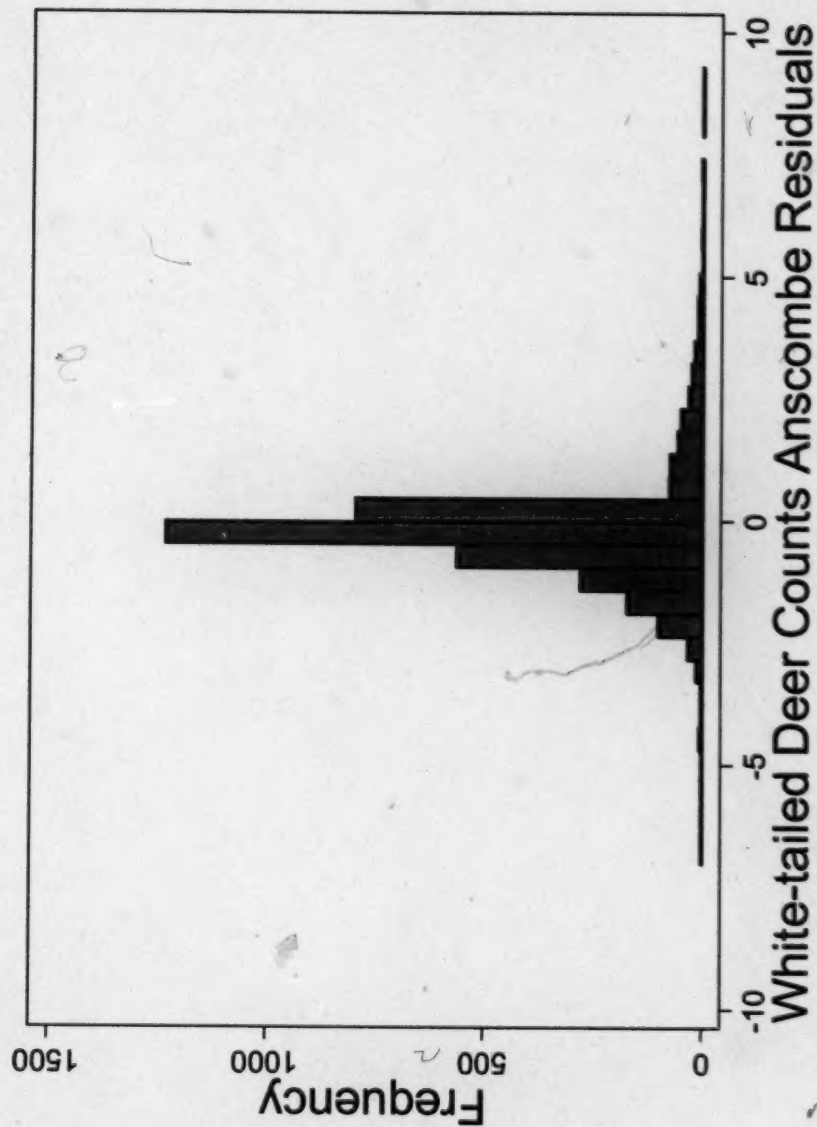


Figure 2.19: Histogram of white-tailed deer count Anscombe residuals for the analysis of white-tailed deer counts within sample sites in northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1969 to 2001.

Table 2.1: Independent variables considered in the analysis of changes in moose and white-tailed deer counts, as derived from surveys conducted by Alberta Sustainable Resource Development from 1969 to 2001. Mean, median and range provided for continuous variables and the number of replicates listed for categorical variables.

Variables	Mean (Median)	Range
Area	9.6 (5.2)	2.6-49.8
Mean Township	80 (82)	57-92
Mean Range	12 (11)	3-26
Township	80 (77)	54-126
Range	12 (11)	1-27
Year	10 (7)	1-33
		(1969 -2001)
Variables	Replicates	
Directed, Fixed-wing	304	
Directed, Rotary	75	
Polygon, Rotary	186	
Quadrat, Fixed-wing	89	
Quadrat, Rotary	297	
Transect, Fixed-wing	2140	
Transect, Rotary	513	

Table 2.2: Percent changes in predicted moose and white-tailed deer counts, in relation to the grand mean and holding all other variables constant, given different aerial survey methods from surveys conducted in northeastern Alberta by Alberta Sustainable Resource Development from 1969 to 2001.

Aerial Survey Method	Predicted Percent Change in Moose Counts	P>z	Predicted Percent Change in White- tailed Deer Counts	P>z
Directed, Fixed-wing	-6.0	0.466	-13.6	0.583
Directed, Rotary	80.9	<0.001	148.9	<0.001
Polygon, Rotary	9.0	0.465	104.6	0.001
Quadrat, Fixed-wing	-21.3	0.030	-82.2	<0.001
Quadrat, Rotary	-27.0	<0.001	20.3	0.258
Transect, Fixed-wing	-26.6	<0.001	-24.0	0.060
Transect, Rotary	27.9	0.001	39.6	0.013

Table 2.3: Negative binomial regression results for analysis of relationship between the counts of moose, determined by aerial surveys flown by Alberta Sustainable Resource Development in northeastern Alberta (1969-2001), and survey variables (n=3604; $p < 0.001$; McFadden's Adjusted $R^2 = 0.068$). 95% confidence interval for coefficient provided in brackets.

Variables	Coefficient (95% Confidence Interval)	P>z
Area	0.0755 (0.0660 to 0.0851)	<0.001
Average Township	-0.0248 (-0.0307 to -0.0189)	<0.001
Year	-0.0861 (-0.1057 to -0.0665)	<0.001
Range	0.0059 (-0.0078 to 0.0195)	0.398
Year*Range	0.0019 (0.0008 to 0.0029)	<0.001
Township	0.1805 (0.1268 to 0.2341)	<0.001
Township ²	-0.0011 (-0.0014 to -0.0008)	<0.001
Directed, Rotary	0.5929 (0.3479 to 0.8380)	<0.001
Polygon, Rotary	0.0864 (-0.1456 to 0.3185)	0.465
Quadrat, Fixed-wing	-0.2399 (-0.4572 to -0.0226)	0.030
Quadrat, Rotary	-0.3143 (-0.4746 to -0.1540)	<0.001
Transect, Fixed-wing	-0.3099 (-0.4348 to -0.1849)	<0.001
Transect, Rotary	0.2463 (0.1042 to 0.3885)	0.001
Constant	-4.0279 (-6.2170 to -1.8389)	<0.001

Table 2.4: Negative binomial regression results for analysis of relationship between counts of white-tailed deer, determined by aerial surveys flown by Alberta Sustainable Resource Development in northeastern Alberta (1969-2001), and survey variables (n=3604; p<0.001; McFadden's Adjusted R²=0.201). 95% confidence interval for coefficient provided in brackets.

Variables	Coefficient (95% Confidence Interval)	P>z
Area	0.0886 (0.0737 to 0.1035)	<0.001
Township	-0.3316 (-0.4183 to -0.2450)	<0.001
Year	-1.2799 (-2.0196 to -0.5403)	0.001
Year ²	0.0398 (0.0175 to 0.0621)	<0.001
Township*Year	0.0234 (0.0120 to 0.0348)	<0.001
Township*Year ²	-0.0007 (-0.0010 to -0.0003)	<0.001
Directed, Rotary	0.9120 (0.3986 to 1.4254)	<0.001
Polygon, Rotary	0.7158 (0.2880 to 1.1436)	0.001
Quadrat, Fixed-wing	-1.7264 (-2.4611 to -0.9916)	<0.001
Quadrat, Rotary	0.1849 (-0.1356 to 0.5053)	0.258
Transect, Fixed-wing	-0.2742 (-0.5599 to 0.0115)	0.060
Transect, Rotary	0.3337 (0.0703 to 0.5970)	0.013
Constant	19.2097 (13.5455 to 24.8740)	<0.001

Moose (*Alces alces*) and White-tailed Deer (*Odocoileus virginianus*) Abundance in Relation to Cumulative Impacts: A Spatial Analysis

Introduction

Cumulative effects are the additive and interactive effects of stressors acting at different temporal and geographic scales within the ecosystem (Alberta Environment 2003). These stressors are not necessarily mutually exclusive of each other and may come from multiple sources (Bonnell and Storey 2000). Additionally, effects may accumulate through additive or multiplicative processes (Bonnell and Storey 2000). No matter the form in which they manifest, cumulative impacts can create a variety of ecological opportunities for differently adapted species (White and Harrod 1997).

The cumulative effects of multiple resource users have impacted Alberta's northeast landscape, potentially leading to the loss and modification of those habitat components needed by some ungulate species to ensure healthy populations (Wishart et al. 1993). In addition to direct habitat loss, landuse disturbances that create cumulative impacts can also open access into previously remote areas. This results in an additional risk factor as ungulates are further exposed to additional hunting pressures from both people and animal predators (AEP 1998, Schneider 2002). MacKendrick et al. (2001) noted that the tendency for the Alberta provincial government to allocate multiple resources to a range of users on the same land base, while at the same time regulating these uses separately, may exacerbate cumulative impacts.

The potential relationship of cumulative impacts from multiple human landuses to moose (*Alces alces*) and white-tailed deer (*Odocoileus virginianus*) abundance has not been examined, despite increasing interest in the effects of cumulative impacts and the importance of these species in Alberta. As well, observed relationships between these ungulates and individual disturbances due to human landuse have varied in the literature. For example, some studies have concluded that forest harvesting can be beneficial to these ungulates by providing suitable browse (Cole 1987, Forbes and Theberge 1993) and some studies have noted that there can be

detrimental effects due to the removal of protection from predators, as well as the creation of access (Cole 1987, Rempel et al. 1997). The presence of corridors, from roads, pipelines or seismic lines, also have debatable effects. The effects, especially from roads, range from eliciting negative responses in the abundance of moose and white-tailed deer, potentially due to the destruction of habitat, impeding movement, vehicular accidents and increased hunter access (Bennett 1991, Forman and Alexander 1998, Rempel et al. 1997), to having a positive response, potentially resulting from the provision of suitable forage and movement corridors (Bennett 1991). Additionally, agricultural lands and areas near human settlement have been found to serve as refugia, providing protection from hunting and predators (Foster et al. 1997, Hayes and Gunson 1995). Agriculture can also provide suitable forage for deer, though land development results in the destruction of habitat and increased access (Stelfox and Stelfox 1993, Wishart et al. 1993). In part, the discrepancies observed in the literature may be due to the range of both positive and negative effects that human landuse can have on moose and white-tailed deer.

The objective of my study was to determine the relationships between ungulate abundance in northeastern Alberta, specifically moose and white-tailed deer, and cumulative impacts resulting from forestry, energy and agricultural disturbances. For my analysis space was substituted for time to achieve a range of industrial disturbances. As such, areas with relatively little disturbance would be considered young in their industrial development trajectory in comparison to those with more disturbance. In conducting this analysis, I intended to determine how moose and white-tailed deer abundance correlated to cumulative impacts arising from single disturbance types, as well as the additive and multiplicative effects of multiple disturbances. By identifying those aspects of cumulative impacts that exhibit the strongest relationship to moose and white-tailed deer, managers can work towards mitigating and decreasing the effect of these disturbances on these ungulates (MacKendrick et al. 2001).

In addition to considering the relationship between cumulative impacts and ungulate abundance, I also took into consideration other variables that may influence the distribution or abundance of moose and white-tailed deer. Distance measurements were included in this study in order to determine if moose and white-tailed deer abundance changed based on their proximity to potential disturbance agents, and if so how. Habitat variables were included, as habitat influences both the likelihood of observing ungulates and of ungulates being present due to shelter and food preferences. Geographical coordinates were also considered in the model to account for any latitudinal and longitudinal spatial gradients.

Methods

Study Area

All data collection was limited to the boreal forest within northeastern Alberta (Figure 3.1) (AEP 1998). This area extends from longitude 110.0°W to approximately longitude 114.0°W and north of latitude 53.4°N to latitude 58.0°N. The northeast region of Alberta was selected for this study because of the rapid development of the forestry and the energy sectors. To date, a large portion of provincial lands in the boreal forest have been leased to various private sector groups of which (in terms of area and potential ecological consequences) the petroleum and forestry industries are the most significant (AEP 1998). A given area of land might have a Forest Management Agreement (FMA) holder, several forest quota holders and many petroleum companies, all operating concurrently and independently (Schneider 2002). Often, many oil and gas leaseholders exist in one township (Schneider 2002). In addition, in the last decade, competition between agriculture and forestry for the use of Alberta's land resource has become increasingly apparent, with agriculture continuing to enlarge at the expense of the forested areas (AEP 1998). Within this region, those areas that had been surveyed for ungulates between 1998

and 2002 by Alberta Sustainable Resource Development were selected as potential sample sites for this study.

Ungulate Abundance

This study used ungulate counts derived from the aerial surveys conducted by Alberta Sustainable Resource Development. I focused my analysis on moose and white-tailed deer, as these species are the preferred game species in northeastern Alberta and influence ecosystem dynamics (see Chapter 1 and 2). As well, the most data were available for these species from the aerial surveys (Found 2001, Hubbs 2002, Kunas 1998, Kunas 2000, Saker 1998, Saker 1999, Saker 2000a, Saker 2000b, Unknown 1999, Unknown 2000). In total, 100 sample sites were considered, ranging in size from 20.4 km² to 58.6 km² and averaging 37.9 km². All ungulate counts were obtained from polygon surveys flown by a rotary aircraft. Sample sites were laid out within wildlife management units (WMUs) on a latitude-longitude grid and were selected and surveyed based on a modified Gasaway technique (Gasaway et al. 1986). WMUs were preliminarily surveyed using fixed-wing aircraft to determine relative abundances of ungulates. The area was then stratified based on sightings of the ungulate for which the survey was intended, into high, medium and low categories. Subsets of each strata were randomly selected as sample sites and resurveyed with a helicopter to get an abundance estimate. I used the number of moose and deer counted within each sample site from 1998 to 2002 divided by the area surveyed as my dependent variable. The area surveyed was defined as the square kilometres flown within the sample site and was provided in the survey reports. None of the sample sites were surveyed more than once.

Landuse Variables

Landuses examined in my analysis included agricultural lands, cutblocks, roads, other linear features and wellsites. All landuse variable values were derived from GIS layers, using

ArcView 3.2, by calculating the level of disturbance within the sample site polygons (ESRI 2000). The percent area coverage of cutblocks and agriculture within a sample site were derived from the Alberta Ground Cover Classification (AGCC) data layer. The AGCC data layer was created from satellite images collected in 1998 and 1999, as well as from data provided by Alberta Environment (AEP 1999). Within the AGCC data layer, cutblocks were defined as being graminoid or undifferentiated. The percent coverage of cutblocks was calculated after subtracting agriculture from the landbase. Agriculture was defined as both croplands and agricultural clearings. The density of wells, roads and other linear features within a sample site, were derived from Alberta Base Features GIS layers. The Alberta Base Features GIS layers were created from data collected for the year 2001 (Alberta Environment 2001). Wells included both active and abandoned sites. Roads included all truck trails, unimproved, graveled, and paved routes. Linear features included pipelines, seismic lines and transmission lines. These density measurements were expressed as km/km^2 , with the exception that wellsites were expressed as the number of wells/ km^2 .

Distance Variables

Additional variables included in this analysis were the distance between the centre of each sample site and the nearest major highway, Métis or native reserves and urban centre. Major highways were paved roads and were derived from an Alberta Base Features GIS layer (Alberta Environment 2001). The location of Métis or native reserves were taken from an atlas GIS layer of native reserves derived from National Topographic Series maps at a scale of 1:250,000 and International Map of the World Series maps at a scale of 1:1,000,000 (Geomatics Canada 1992). The layer of native reserves was digitized to reflect the location of Métis reserves. Locations of Métis reserves were derived from Alberta provincial base maps (ASRD 2002). Urban centres were towns or cities, which were gathered from an atlas GIS layer (Government of Canada 2003). All attribute data for this layer were obtained from the Canadian Geographical Names Data Base.

Habitat Variables

Data for habitat variables within each of the sample sites were taken from the Alberta Ground Cover Classification GIS layer (AEP 1999). Specific variables recorded were the proportion of the sample site, excluding agricultural areas, that was water, closed coniferous forest, closed deciduous forest, closed mixedwood forest, open coniferous forest, open deciduous forest, open mixedwood forest, shrubs and wetlands. For the Alberta Ground Cover Classification GIS layer, closed forests were defined as having > 40 % crown closure, while open forests had 6 to 40 % crown closure. Coniferous forests included black spruce (*Picea mariana*), white spruce (*Picea glauca*), undifferentiated pine and undifferentiated conifer. Deciduous stands were composed of aspen (*Populus tremuloides*), balsam poplar (*Populus balsamifera*) and birch (*Betula papyrifera*). Mixedwood stands had between 20 to 80 % mixed wood cover, with closed stands having > 50 % crown closure and open stands having 6 to 50 % crown closure. Shrubland was defined as having > 25 % shrubs and < 6 % tree cover. Wetlands were composed of emergent wetlands, graminoid wetlands, shrubby wetlands, black spruce bogs and undifferentiated wetlands. Additional habitat variables that were excluded from the analysis due to their low level of coverage were grasslands and upland dunes.

Additional Variables

In addition to habitat and landuse variables, spatial coordinates were also included in this analysis. Spatial coordinates were measured in latitude and longitude and were derived from the northwest corner of each polygon. These coordinates were included to account for latitudinal and longitudinal spatial gradients.

Statistical Analysis

Descriptive analysis of the data, including calculation of medians and ranges, was used to examine potential similarities between the sample sites I selected and the landuse disturbances in

northeastern Alberta. Before modelling the relationship between cumulative impacts and ungulate abundance, I calculated the correlation coefficients between each combination of the independent variables. Due to high correlation coefficients between several landuse and distance variables (Table 3.1), subsets of the data were selected for further analysis (Figure 3.1). Subsets were based on the level of agricultural coverage within the sample sites, which was subjectively selected as being divided into sites with agricultural coverage from 20 to 80 % and sites with agriculture coverage of < 20 %. Those samples with 20 to 80 % agricultural coverage were used in the "southern sub-region" analysis. Sample sites with less than 20 % agriculture were used in the "northern sub-region" analysis. Some sample sites were not included in further analyses as their inclusion led to correlations between the variables of interest. Within the sub-regions, I calculated the correlation coefficients between each combination of the independent variables. I considered any combination of variables exhibiting a correlation coefficient of ≥ 0.70 highly correlated (Cohen et al. 2000) and chose not to include these variables in the model together. In these cases, only the variable with the highest R^2 value from an univariate regression analysis with ungulate abundance was included in further analysis.

To determine the relationship between cumulative impacts and ungulate abundance in northeastern Alberta, I modeled moose and white-tailed deer abundance separately. A continuous variable for ungulate abundance was used instead of the count data, as in Chapter 2, because the distributions of the count data for two of the sub-region models did not match either Poisson or negative binomial distributions. However, both the moose and white-tailed deer abundance were Box-Cox transformed due to the skewed nature of the abundance data. The transformed data was used in an attempt to normalize the distribution of the residuals and in doing so, meet an assumption of linear regression models (Mateu 1997). Linear regression analyses between ungulate abundance and each individual landuse variable were conducted first for both sub-regions to identify those variables that exhibited a significant relationship with ungulate

abundance, indicating cumulative effects arising from the increased presence of that variable on the landbase. Linear regression analyses between ungulate abundance and each individual distance variable were also conducted. For these analyses, all habitat variables were included in the model, along with spatial coordinates. Variables were then removed based on their p-value using a backwards-stepwise modeling approach until all variables remaining in the model were significant to $p < 0.15$ or until the landuse or distance variable of interest would be removed (Hosmer and Lemeshow 2000). At the end of the procedure, each dropped variable was re-entered into the model to check for confounding variables (Hosmer and Lemeshow 2000). Any variable re-entered that resulted in a coefficient change of $\geq 20\%$ in the model variables was included in the model.

In order to determine the additive and multiplicative cumulative effects of the landuse factors, another model was built for each ungulate species in both sub-regions using all landuse, distance and habitat variables. Spatial coordinates were also included in these models. Linear regression models were conducted using the same backwards-stepwise modeling approach as above, except that variables were removed based on their p-value until all variables remaining in the model were significant to $p < 0.15$, allowing for landuse and distance variables to drop from the model (Hosmer and Lemeshow 2000). Finally, non-linearities in landuse and distance variables were considered by including the quadratics of each variable and testing for significance. Interactions between landuse and distance variables were also considered, as they were indicative of multiplicative cumulative effects. The model results were then used to determine the expected change in ungulate abundance over the range of each of the remaining landuse and distance variables. Finally, residual plots of residuals against fitted values and histograms of the residuals were created to assess the fit of the final models. All analyses were conducted at the scale of the sample site as this was the smallest scale for which I could collect ungulate data and this scale could reveal local effects of cumulative impacts. As well, scaling up

would have resulted in a low sample size. All analyses were conducted in STATA (StataCorp 2004).

Results

Composition of Landscape and Correlation Analysis

Agriculture was the most prevalent land-cover type within all sample sites, making up 27 % of the total coverage. Individual sample sites ranged from having 0 to 86 % coverage of agriculture, comparable to townships throughout the northeast region having 0 to 90 % coverage (Table 3.2). However, the median percent coverage of agriculture within sample sites was 22 % higher than at the regional level, indicating that agriculture was more overly represented in the sample sites than occurs in the entire northeast section of Alberta. Within the sub-regions, agriculture ranged from 20 to 80 % coverage in the south and from 0 to 20 % in the north, covering the majority of the range of agriculture found in the northeast (Table 3.3). Clearcuts made up < 1% of the total coverage within the sample sites, with the range of clearcut coverage within the sample sites (0 to 10 %) only representing the lower range of the clearcut coverage observed at the regional scale (0 to 32 %). However, clearcut coverage at both the sample site and regional scale had a median of zero, indicating that they are relatively rare on the landbase currently. Within the sub-regions, only one sample site contained a clearcut in the south and clearcuts ranged from 0 to 10 % coverage in the north. The range of clearcut coverage found in all sample sites within the northeast was covered with the northern sub-region.

Within all sample sites, linear features, excluding roads, were prevalent, occurring at a median density of 1.72 km/km² (Table 3.4). At the regional scale, linear features were also the most prevalent linear feature with a median density of 1.31 km/km². However, the sample sites did not capture the full range of linear feature density that occurs at the regional scale, with sample site densities ranging from 0 to 4.50 km/km² and regional densities ranging from 0 to 6.18

km/km². Linear density was also prominent in both sub-regions with a median density of 1.75 and 2.42 km/km² for the south and north regions respectively (Table 3.5). The range of linear density found in all sample sites within the northeast was covered within the sub-regions. Within all northeast sample sites, road density had a median density of 0.63 km/km². This median was 1.4 times higher than that found at the regional scale. However, the range of road density was higher at the regional scale at 0 to 2.60 km/km², instead of 0 to 1.67 km/km². Again, the range of road density found in all sample sites within the northeast was covered within the sub-regions, with the median density higher in the south (0.95 km/km²) than in the northern sub-region (0.18 km/km²). The median of wellsite density at the sample site and regional scale was comparable at 0.39 and 0.31 wells/km² respectively, though the range for wellsite density within the sample sites (0 to 2.75 wells/km²) was lower than that observed at the regional scale (0.01 to 26.20 wells/km²). Again, the range of wellsite density found in all sample sites within the northeast was covered within the sub-regions, with the median density higher in the south (0.47 wells/km²) than in the northern sub-region (0.32 wells/km²).

The median of distance to major highway for all sample sites in the northeast was 6.58 km, ranging from 0 to 104.44 km (Table 3.4). The range of distance to major highway found in all sample sites within the northeast was covered within the sub-regions, with the median distance higher in the north (12.81 km) than in the southern sub-region (6.58 km) (Table 3.5). The median of distance to native/Métis reserves for all sample sites in the northeast was 51.88 km, ranging from 0 to 114.07 km. The range of distance to native/Métis reserves found in all sample sites within the northeast was not covered within the sub-regions, with the furthest distance only at 96.07 km within the northern sub-region. The median distance was again higher in the north (59.70 km) than in the southern sub-region (29.75 km). The median of distance to urban centre for all sample sites in the northeast was 35.72 km, ranging from 5.70 to 128.87 km. The range of distance to urban centre found in all sample sites within the northeast was covered within the sub-

regions, with the median distance higher in the north (55.79 km) than in the southern sub-region (27.77 km).

Strong correlations were observed between several variables in the southern sub-region (Table 3.6). Longitude and distance to native/Métis reserves had a correlation coefficient of -0.87. Longitude and shrub coverage had a correlation coefficient of 0.70. Distance to native/Métis reserves and open mixedwood had a coefficient of -0.73. The regression analyses for moose abundance indicated that longitude had a higher R^2 value ($R^2 = 0.555$) than distance to native/Métis reserves ($R^2 = 0.476$) or shrub coverage ($R^2 = 0.149$). As well, distance to native/Métis reserves had a higher R^2 value ($R^2 = 0.476$) than open mixedwood ($R^2 = 0.342$). Given these relationships, longitude and open mixedwood were included in the southern region model for moose, as longitude had a higher R^2 value than distance to native/Métis reserves and open mixedwood was not correlated to longitude. The regression analyses for white-tailed deer indicated that distance to native/Métis reserves had a higher R^2 value ($R^2 = 0.169$) than longitude ($R^2 = 0.070$) or open mixedwood coverage ($R^2 = 0.168$). As well, longitude had a higher R^2 value ($R^2 = 0.070$) than shrubs ($R^2 = 0.021$). Given these relationships, distance to native/Métis reserves and shrubs were included in the southern region model for white-tailed deer, as distance to native/Métis reserves had a higher R^2 value than longitude and shrub coverage was not correlated to distance to native/Métis reserves.

Strong correlations were observed between latitude and open mixedwood coverage in the northern sub-region ($r = -0.72$). The regression analyses for moose abundance indicated that latitude had a higher R^2 value ($R^2 = 0.480$) than open mixedwood ($R^2 = 0.163$). The regression analyses for white-tailed deer abundance indicated that latitude had a higher R^2 value ($R^2 = 0.706$) than open mixedwood ($R^2 = 0.471$). Given these relationships, latitude was included in the northern region model for both moose and white-tailed deer.

Analysis of Moose Abundance

In the southern region, analyses of individual landuse and distance variables indicated that the only significant relationship was the negative relationship observed between moose abundance and agriculture ($p=0.003$) (Figure 3.2). The model of moose abundance in relationship to all landuse and distance variables in the southern region resulted in an adjusted R^2 value of 0.71 ($p<0.001$) (Table 3.7). The final formula was:

$$\begin{aligned} \text{Moose Abundance} = & 147.0727 + (2.6336 * \text{Longitude}) + (0.0118 * \text{Longitude}^2) + (-0.0172 * \text{Well} \\ & \text{Density}) + (-0.0253 * \text{Road Density}) + (-0.0857 * \text{Agriculture}) + (-0.2781 * \text{Closed Coniferous}) + \\ & (-0.2127 * \text{Closed Deciduous}) + (-0.1372 * \text{Water}) + (-0.3672 * \text{Open Mixedwood}) + \\ & (0.0482 * \text{Open Deciduous}) + (-0.0521 * \text{Wetland}) \end{aligned}$$

Agriculture coverage again had a negative relationship to moose abundance ($p=0.012$). Well density was statistically significant until the inclusion of confounding variables. Inclusion of confounding variables resulted in a non-significant relationship, although the negative trend between well density and moose abundance remained ($p=0.066$). The relationships observed indicated that, holding all other variables constant, moose abundance declined by 0.05 moose/km² over the range of agricultural coverage observed in the southern region. Over the range of well density observed in the southern region, moose abundance declined by 0.05 moose/km². All of the landuse variables remaining in the model exhibited the same direction of relationship to moose counts as was observed in the regression analyses of individual landuse variables (Figure 3.2). No multiplicative cumulative effects were observed.

In the northern region, analyses of individual landuse and distance variables indicated that moose abundance was not significantly related to any landuse or distance variables (Figure 3.3). The model of moose abundance in relationship to all landuse and distance variables in the northern region resulted in an adjusted R^2 value of 0.61 ($p<0.001$) (Table 3.8). The final formula was:

$$\begin{aligned} \text{Moose Abundance} = & 4.4166 + (-0.0576 * \text{Latitude}) + (0.0072 * \text{Longitude}) + \\ & (-0.1306 * \text{Well Density}) + (0.0052 * \text{Linear Density}) + (0.0008 * \text{Distance to Native Reserve}) + \end{aligned}$$

$$(-0.0016 * \text{Distance to Urban Centre}) + (-0.3183 * \text{Closed Coniferous}) + \\ (-0.6027 * \text{Closed Mixedwood}) + (-0.2108 * \text{Water}) + (0.0075 * \text{Open Coniferous})$$

Again none of the landuse or distance variables were significantly related to moose abundance.

In considering the fit of both sub-region moose models that considered additive and multiplicative cumulative impacts, it is apparent that the residuals are not constant in variance (Figure 3.4 and Figure 3.5). As well, histograms of the residuals indicate that the residuals for both moose models are not normally distributed (Figure 3.6 and Figure 3.7).

Analysis of White-tailed Deer Abundance

In the southern region, analyses of individual landuse and distance variables indicated that white-tailed deer abundance was negatively related to agriculture ($p=0.01$) and distance to urban centres ($p=0.04$) (Figure 3.8). White-tailed deer abundance was positively related to road density ($p=0.005$) and linear density ($p=0.09$). The model of white-tailed deer abundance in relationship to all landuse and distance variables in the southern region resulted in an adjusted R^2 value of 0.50 ($p<0.001$) (Table 3.9). The final formula was:

$$\text{Deer Abundance} = 25.2343 + (-0.4456 * \text{Latitude}) + (-0.1954 * \text{Well Density}) + \\ (0.3776 * \text{Road Density}) + (-1.2398 * \text{Agriculture}) + (-0.0108 * \text{Distance to Urban Centre}) + \\ (2.7409 * \text{Water}) + (1.8547 * \text{Closed Deciduous})$$

Agriculture coverage ($p<0.001$), distance to urban centre ($p=0.02$) and well density ($p=0.06$) had a negative relationship to white-tailed deer abundance. Road density exhibited a positive relationship to white-tailed deer abundance ($p=0.06$). The relationships observed indicated that, holding all other variables constant, over the range of agricultural coverage observed in the southern region, white-tailed deer abundance declined by 1.66 deer/km². A decline in white-tailed deer abundance of 0.73 deer/km² over the range of the distance from urban centres was also observed in the southern region. Over the range of well density observed in the southern region, white-tailed deer abundance declined by 0.67 deer/km². Over the range of road density observed in the southern region, white-tailed deer abundance increased by 0.99 deer/km².

All of the landuse and distance variables remaining in the model exhibited the same direction of relationship to white-tailed deer counts as was observed in the analyses of individual landuse variables (Figure 3.8). No multiplicative cumulative effects were observed.

In the northern region, analyses of individual landuse and distance variables indicated that white-tailed deer abundance was negatively related to cutblock coverage ($p=0.01$) and distance to urban centres ($p=0.08$) (Figure 3.9). The model of white-tailed deer abundance in relationship to all landuse and distance variables in the northern region resulted in an adjusted value of 0.86 ($p<0.001$) (Table 3.10). The final formula was:

$$\begin{aligned} \text{Deer Abundance} = & 0.9466 + (-0.0456 * \text{Latitude}) + (-0.0151 * \text{Longitude}) + (-0.3940 * \text{Cutblock}) + \\ & (0.0367 * \text{Road Density}) + (-0.0005 * \text{Distance to Native Reserve}) + \\ & (-0.0007 * \text{Distance to Urban Centre}) + (0.0001 * \text{Distance to Major Highway}) + (0.1058 * \text{Shrub}) + \\ & (0.1194 * \text{Closed Deciduous}) + (0.1895 * \text{Open Coniferous}) \end{aligned}$$

Distance to urban centre ($p=0.005$) again had a negative relationship to white-tailed deer abundance. The relationships observed indicated, holding all other variables constant, over the range of the distance from urban centres, white-tailed deer abundance declined by 0.10 deer/km². All of the landuse and distance variables remaining in the model exhibited the same direction of relationship to white-tailed deer counts as was observed in the analyses of individual landuse variables (Figure 3.9).

In considering the fit of both sub-region white-tailed deer models that considered additive and multiplicative cumulative impacts, it is apparent that the residuals are not constant in variance (Figure 3.10 and Figure 3.11). As well, histograms of the residuals indicate that the residuals for both white-tailed deer models are not normally distributed (Figure 3.12 and Figure 3.13).

Discussion

Both moose and white-tailed deer abundance showed significant relationships to cumulative impacts arising from single disturbance types. In the southern region, both moose and white-tailed deer abundance declined with increasing cumulative impacts arising from agriculture

coverage. The relationship with moose may be due to increasing agriculture being associated with decreased habitat availability from the removal of natural food and cover (Nietfeld et al. 1985). However, a study by Schneider and Wasel (2000) found that the highest densities of moose have been recorded in the agricultural zone of Alberta, with a linear decline in moose density with distance from the agricultural zone. The contrast observed between my study and that of Schneider and Wasel's may be due to the study locations being different, as Schneider and Wasel were considering agriculture in western Alberta. Conversely, in my study, agriculture was found primarily in the southern region sample sites. Therefore, the difference in the results could be a result of different characteristics in the agricultural coverage found in these locations. The decline in white-tailed deer observed with increasing cumulative impacts arising from agriculture coverage is contradictory to that which would be expected given their habitat preferences. White-tailed deer are known to adapt well to human environments and thrive in complex fragmented habitats, foraging on cultivated forage and cereal crops (AEP 1998, Stelfox and Stelfox 1993). The reason for the observed relationship may be that white-tailed deer still require cover that is not available at high intensities of agricultural coverage. Shelter is required both for escape cover from predators and in the winter for providing thermal cover (Renecker and Hudson 1993, Stelfox and Stelfox 1993). Therefore, at low agricultural coverage, white-tailed deer abundance should exhibit a positive relationship to agriculture. In the southern region, white-tailed deer abundance additionally was positively related to the cumulative impacts arising from increasing road density. Given the foraging preferences of white-tailed deer, the grasses along the road edge may be an attractive food source (Bennett 1991). As such, roads may be acting as part of the human-mediated expansion of white-tailed deer (Bayne et al. 2004).

In the northern region, moose abundance showed no relationship to the cumulative impacts of individual landuse variables. This may have been due to the low levels of most landuses found in the region. However, white-tailed deer abundance declined with cumulative

impacts arising from increasing cutblock coverage. Forestry developments in Alberta have increased over the last 20 years (MacKendrick et al. 2001, Schneider 2002). Large forest clearcuts may create an abundance of herbaceous forage for a few decades, but may not be used by ungulates because of inadequate cover from predators, human harassment or inclement weather (Wishart et al. 1993). The negative relationship between white-tailed deer and cutblocks mirrors observed relationships between white-tailed deer and agriculture in the southern region, in that while deer may be expected to respond favourably to the presence of open habitat, in the winter months this may be selected against due to shifted habitat preferences. This is supported by Secord et al. (1999) who found that deer avoided non-forested areas during the winter and increased their use of these areas with warmer weather.

In considering cumulative effects arising from multiple landuses, additive effects were observed but no multiplicative effects. However, many of the observed additive relationships resulted in only small changes in the abundance of moose and white-tailed deer. In the southern region, additive effects arose from well density and agricultural coverage for moose abundance. White-tailed deer abundance responded to the additive effects of well density, road density and agricultural coverage. The appropriateness of the relationships between these ungulates and agriculture and road density has already been discussed above. The relationship between the petroleum industry and ungulates has not been studied to any great extent, even though this industry has left the most pervasive and intense ecological footprint of any human activity in the entire boreal forest region (AEP 1998). The oil and gas industry annually disturbs almost the same area of forest as the forest industry (Schneider 2002), yet there have been few studies on the effects of wellsite density on ungulates. In Alberta, the number of cumulative oil and gas wells completed has been rapidly increasing since the mid-1970s, with a great deal of development in the last few decades in northeastern Alberta (Schneider 2002). This rapid expansion could potentially have serious consequences for ungulate abundance, as it may result in the loss of

habitat and increased human activity. This is supported by the model results, which found that both moose and white-tailed deer abundance declined with increased well density.

In the northern region, both moose and white-tailed deer abundance showed no significant relationship to additive or multiplicative cumulative effects. The lack of any relationship may have been due to the low level of many landuses in the region.

The lack of any significant relationship between ungulates and the cumulative effects arising from linear feature density was unexpected given that linear features were so pervasive in both the southern and northern sub-regions. There has been a steady increase in the cumulative length of linear features developing on the landscape in northern Alberta. Seismic lines increase the proportion of young forest, reduce average patch size, and increase human access (Schneider 2002). The lack of any relationship warrants further consideration.

The relationship between ungulates and human influence was further addressed through consideration of distance variables. The only distance variable that showed a significant relationship to ungulate abundance was distance to urban centre. The relationship observed between white-tailed deer abundance and distance to urban centres can be interpreted as indicating that abundance was higher closer to urban centres. This relationship may be due to urban areas providing a safe haven from predator and hunting pressures. Foster et al. (1997) found that deer in counties in Illinois with high non-metropolitan human population densities tended to be less susceptible to hunter harvest than deer in less densely populated counties. As well, for white-tailed deer, it may be indicative of their propensity to expand with the influence of human developments (Bayne et al. 2004).

The lack of a significant relationship between ungulates and the distance to highways or native/Métis reserves was unexpected given the results from previous studies. Schneider and Wasel (2000) found that moose abundance was predicted to be higher closer to major highways. As well, native hunting has been regarded as very important to causing the declines of ungulates

and there have been concerns raised related to aboriginal harvesting (Wishart et al. 1993, Todd and Lynch 1992). The lack of any observed relationship to the distance to native/Métis reserves was complicated by its correlation to longitude and open mixedwood coverage in the southern region. Given the contradictions in my results versus previous studies, further research into these relationships is necessary.

The approach I took in analyzing the composition of cumulative impacts allows for insight into the individual, additive and multiplicative impacts these landuse disturbances may have on the abundance of ungulates. Cumulative effects from multiple resource users are complex, such that analysis of an individual disturbance cannot provide insight into the overall effects that elicit responses in ungulate populations. This study took into consideration the complex nature of human landuse by considering multiple human landuse disturbances. However, high correlations between some of my variables limited my ability to interpret patterns, particularly with the distance to native reserves in the southern sub-region. Additionally, while these analyses suggest potential relationships that may exist between each of moose and white-tailed deer and cumulative impacts, further studies need to be conducted in order to validate my results. This is particularly necessary, given that the assumptions of my models were not met, namely that the residuals were not normally distributed and the residuals did not have constant variance. Therefore, caution is required in the acceptance of these results and in making good predictions, given the lack of model fit. Alternative modeling approaches may improve the model fit, as Box-Cox transforming the abundance data did not help normalize the residuals so that a linear model could be used. The lack of model fit may be reflective of the survey methodology, which was not conducted with this type of analysis in mind. Instead, the sample sites were surveyed with the intention of combining their values to arrive at population estimates over a larger area. A more systematic approach to surveying areas, which sampled across differing levels of landuse disturbance, may provide better data for post-hoc analyses. As well, the lack of model

fit may be improved with an increased sample size for both sub-regions. Additional aerial surveys were completed by Alberta Sustainable Resource Development from 1998 to 2002, however the data had not been entered into reports and were not accessible. An increased sample size may help in identifying relationships that exist but were not found to be significant in this analysis.

Literature Cited

- Alberta Environment. 2001. Alberta Base Features GIS layers. Alberta Environment, Edmonton, Alberta, Canada.
- Alberta Environment. 2003. Northern River Basins Study Final Report.
<http://www3.gov.ab.ca/env/water/nrbs/sect3/sect314.html>
- Alberta Environmental Protection (AEP). 1998. The Boreal Forest Natural Region of Alberta. Alberta Environmental Protection, Edmonton, Alberta, Canada. 313 pp.
- Alberta Environmental Protection (AEP). 1999. Alberta Ground Cover Classification GIS layers. Alberta Environmental Protection, Edmonton, Alberta, Canada.
- Alberta Sustainable Resource Development (ASRD). 2002. Provincial base: 2002 Wildlife Management Unit Map. Alberta Sustainable Resource Development, Edmonton, Alberta, Canada.
- Bayne, E., S. Boutin and R. Moses. 2004. Are boreal forest mammals good indicators of cumulative effects? Sustainable Forest Management Network, Edmonton, Alberta, Canada. 43 pp.
- Bennett, A.F. 1991. Roads, roadsides and wildlife conservation: a review. Pp. 99-117 in Saunders, D.A. and R.J. Hobbs, eds. Nature Conservation 2: The Role of Corridors. Surrey Beatty & Sons, Chipping Norton, Australia. 442 pp.
- Bonnell, S. and K. Storey. 2000. Addressing cumulative effects through strategic environmental assessment: A case study of small hydro development in Newfoundland, Canada. Journal of Environmental Assessment Policy and Management. 2: 477-499.

- Cohen, B.A., R.D. Mitra, J.D. Hughes and G.M. Church. 2000. A computational analysis of whole-genome expression data reveals chromosomal domains of gene expression. *Nature America*. 26: 183-186.
- Cole, G.F. 1987. Changes in Interacting Species with Disturbance. *Environmental Management*. 11: 257-264.
- Environmental Systems Research Institute (ESRI). 1999. ArcView GIS 3.2. ESRI, Redlands, California, U.S.A.
- Forbes, G.J. and Theberge, J.B. 1993. Multiple landscape scales and winter distribution of moose in a forest ecotone. *The Canadian Field Naturalist*. 107: 201-207.
- Found, C. 2001. Aerial Survey for Moose in WMU 509. Alberta Fish and Wildlife, Edmonton, Alberta, Canada.
- Forman, R.T.T. and L.E. Alexander. 1998. Roads and their major ecological effects. *Annual Review of Ecology and Systematics*. 29: 207-231.
- Foster, J.R., J.L. Roseberry and A. Woolf. 1997. Factors influencing efficiency of white-tailed deer in Illinois. *Journal of Wildlife Management* 61: 1091-1097.
- Gasaway, W.C, S.D. Dubois, D.J. Reed and S.J. Harbo. 1986. Estimating moose population parameters from aerial surveys. University of Alaska, Fairbanks, Alaska. 108 pp.
- Geomatics Canada. 1992. alinresg.e00.zip.
<http://geogratis.cgdi.gc.ca/download/atlas/2mprod/al/geog/e00/alinresg.e00.zip>. Geomatics Canada, Ottawa, Ontario, Canada.
- Government of Canada. 2003. National Scale Frameworks Populated Places, Canada.
Government of Canada, Canada.
- Hayes, R.D. and J.R. Gunson. 1995. Status and management of wolves in Canada. Pp. 21-33 in Carbyn, L.N., S.H. Fritts and D.R. Seip, eds. *Ecology and Conservation of Wolves in a Changing World*. Canadian Circumpolar Institute, Occasional Publication No.35. 642 pp.

- Hosmer, D.W. and S. Lemeshow. 2000. *Applied Logistic Regression*. John Wiley and Sons, Inc., New York, New York, U.S.A. 373 pp.
- Hubbs, A. 2002. Aerial Survey for Moose in WMU 510. Alberta Fish and Wildlife, Edmonton, Alberta, Canada.
- Kunnas, F. 1998. WMU 260 White Area Ungulate Survey. Alberta Fish and Wildlife, Edmonton, Alberta, Canada.
- Kunnas, F. 2000. WMU 512 Ungulate Survey. Alberta Fish and Wildlife, Edmonton, Alberta, Canada.
- MacKendrick, N., Fluet, C., Davidson, D., Krogman, N., and Ross, M. 2001. *Integrated Resource Management in Alberta's Boreal Forest: Opportunities and Constraints*. Sustainable Forest Management Network, Edmonton, Alberta, Canada. 29 pp.
- Mateu, J. 1997. Methods of Assessing and Achieving Normality Applied to Environmental Data. *Environmental Management* 21: 767-777.
- Nietfeld, M., J. Wilk, K. Woolnough, and B Hoskin. 1985. Wildlife habitat requirement summaries for selected wildlife species in Alberta. Alberta Energy and Natural Resources, Fish and Wildlife Division, Wildlife Resource Inventory Unit, Canada. 260 pp.
- Rempel, R.S., P.C. Elkie, A.R. Rodgers and M.J. Gluck. 1997. Timber-management and natural-disturbance effects on moose habitat: landscape evaluation. *Journal of Wildlife Management*. 61: 517-524.
- Renecker, L.A. and R.J. Hudson. 1993. Morphology, Bioenergetics and Resource Use: Patterns and Processes. Pp. 141-163 in Stelfox, J.B., ed. *Hoofed Mammals of Alberta*. Lone Pine Publishing, Edmonton, Alberta, Canada. 241 pp.
- Saker, K.A. 1998. WMU 506 Deer/Moose survey. Alberta Fish and Wildlife, Edmonton, Alberta, Canada.

- Saker, K.A. 1999. WMU 518 Moose/deer Survey. Alberta Fish and Wildlife, Edmonton, Alberta, Canada.
- Saker, K.A. 2000a. WMU 501 Deer/Moose Survey. Alberta Fish and Wildlife, Edmonton, Alberta, Canada.
- Saker, K.A. 2000b. WMU 502 Deer/Moose Survey. Alberta Fish and Wildlife, Edmonton, Alberta, Canada.
- Schneider, R.R. 2002. Alternative Futures: Albertas Boreal Forest at the Crossroads. The Federation of Alberta Naturalists, Edmonton, Alberta, Canada. 152 pp.
- Schneider, R.R. and Wasel, S. 2000. The effect of human settlement on the density of moose in northern Alberta. *Journal of Wildlife Management*. 64: 513-520.
- Secord, M.L., P.E. Zager and D.H. Pletscher. 1999. The influence of temporal and spatial factors on clearcut use by white-tailed deer in northern Idaho. *Western Journal of Applied Forestry*. 14: 177-182.
- StataCorp. 2004. Intercooled Stata 8.2 for Windows. StataCorp, Texas, U.S.A.
- Stelfox, J.B. and J.G. Stelfox. 1993. Distribution. Pp. 45-61 in Stelfox, J.B., ed. *Hoofed Mammals of Alberta*. Lone Pine Publishing, Edmonton, Alberta, Canada. 241 pp.
- Todd, A.W. and G.M. Lynch. 1992. Managing Moose in the 1990s and Beyond: Results of a survey of opinions, attitudes and activities of Albertas resident moose hunters. Alberta Environmental Protection, Edmonton, Alberta, Canada. 16 pp.
- Unknown. 1999. WMU 530 Survey. Alberta Fish and Wildlife, Edmonton, Alberta, Canada.
- Unknown. 2000. WMU 506. Alberta Fish and Wildlife, Edmonton, Alberta, Canada.
- White, P.S. and J. Harrod. 1997. Disturbance and Diversity in a Landscape Context. Pp. 128-159 in Bissonette, J.A., ed. *Wildlife and Landscape Ecology: Effects of Pattern and Scale*. Springer-Verlag New York Inc., New York, U.S.A. 410 pp.

Wishart, W.D., J.G. Stelfox, E.S. Telfer and J.R. Gunson. 1993. Management. Pp. 107-118 in
Stelfox, J.B., ed. Hoofed Mammals of Alberta. Lone Pine Publishing, Edmonton, Alberta,
Canada. 241 pp.

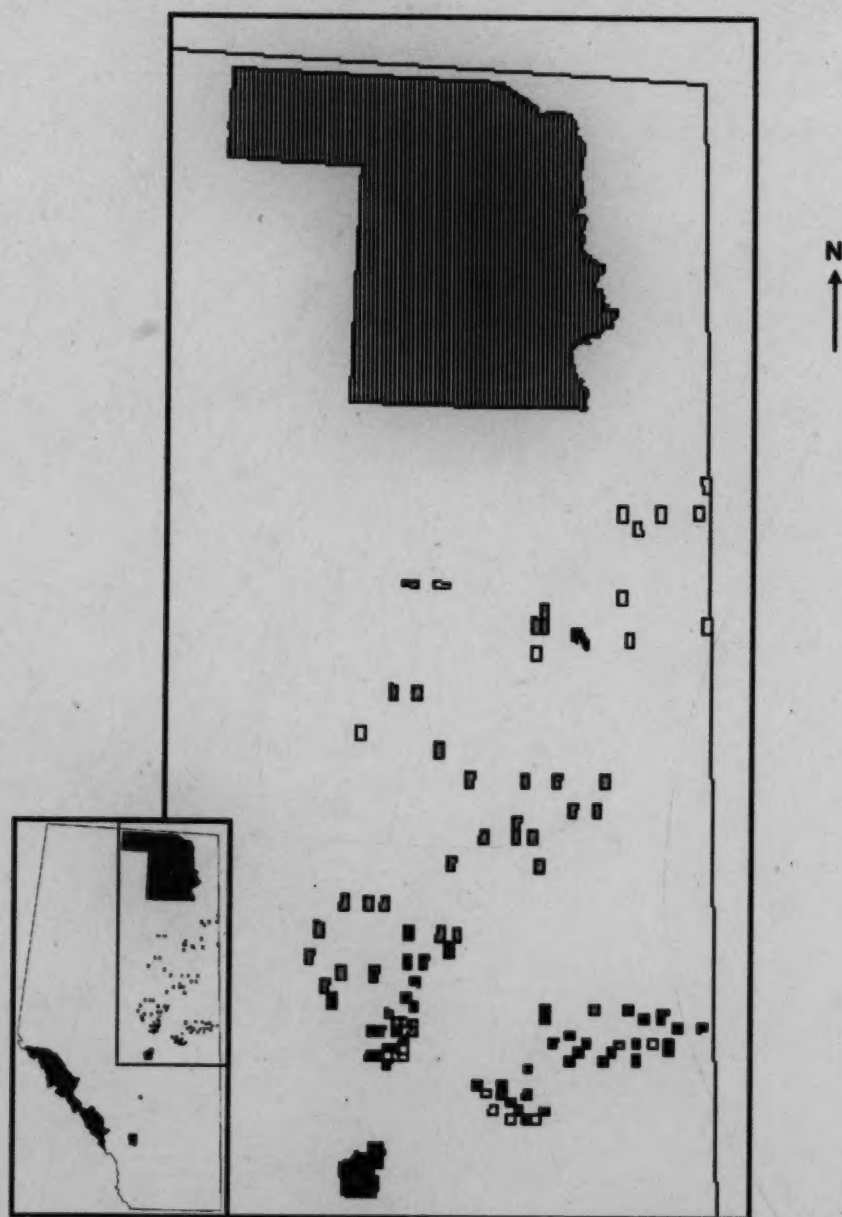


Figure 3.1: Northeastern Alberta study area and sample sites based on ungulate surveys conducted by Alberta Sustainable Resource Development from 1998 to 2002. Inset shows location in Alberta. Sample sites not included in modeling are indicated by white polygons. Sample sites for the analysis of high agricultural coverage (southern sub-region) are indicated by dark grey polygons. Sample sites for the analysis of low agricultural coverage (northern sub-region) are indicated by light grey polygons. Black areas indicate urban centres and striped areas indicate protected areas.

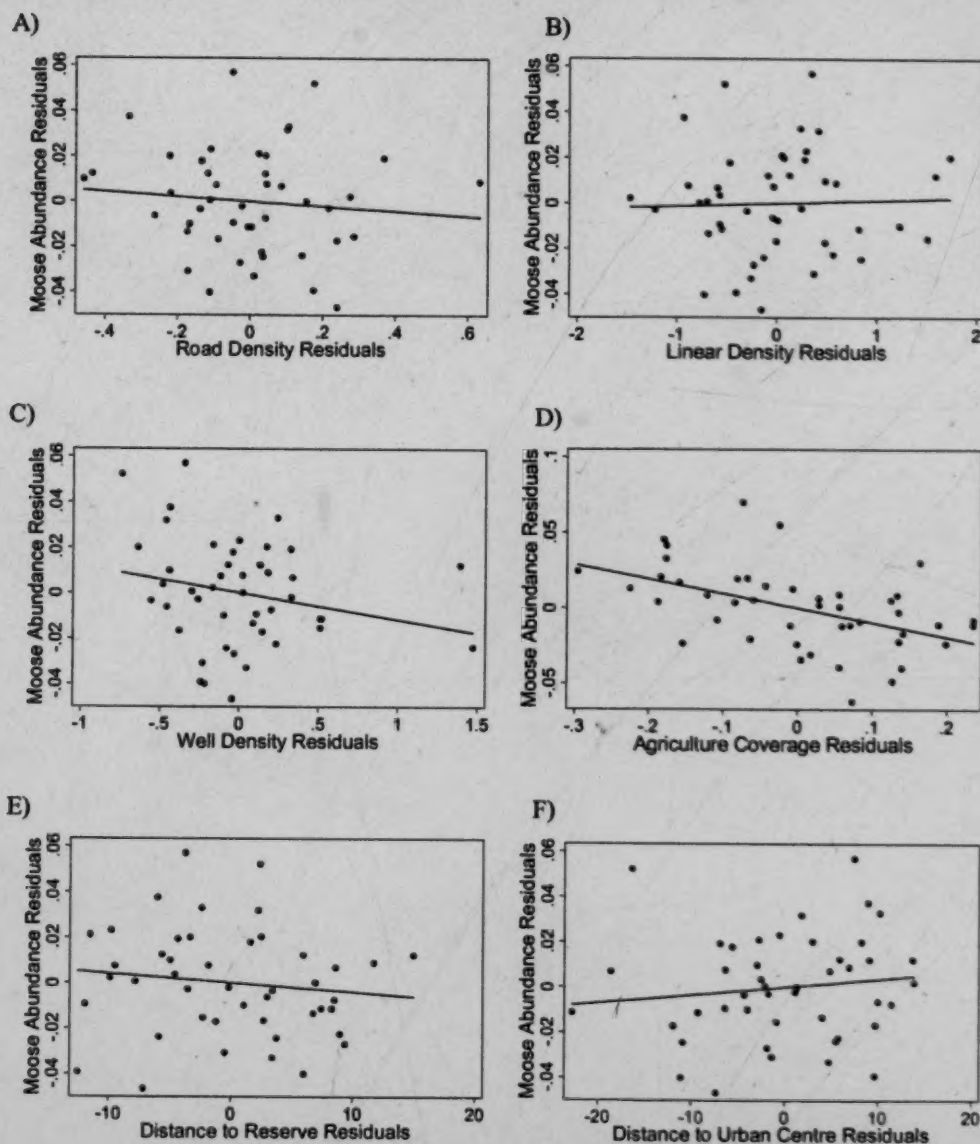


Figure 3.2: Results from regression analyses of moose abundance for the southern sub-region. Moose abundance derived from Alberta Sustainable Resource Development surveys (1998-2002). Partial regression plots shown. P-values, partial R^2 and coefficient listed below. A) Road density ($p=0.60$, $R^2=0.009$, $b= -0.01$). B) Linear density ($p=0.83$, $R^2=0.002$, $b= 0.001$). C) Well density ($p=0.22$, $R^2=0.044$, $b= -0.01$). D) Agricultural coverage ($p=0.003$, $R^2=0.227$, $b= -0.10$). E) Distance to native reserve ($p=0.50$, $R^2=0.014$, $b= -0.0004$). F) Distance to urban centre ($p=0.46$, $R^2=0.017$, $b= 0.0004$). G) Distance to major highway ($p=0.99$, $R^2<0.0001$, $b= 0.00001$).

G)

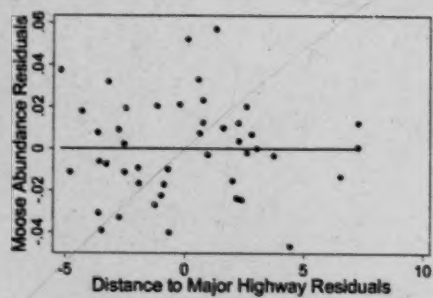


Figure 3.2 continued: Results from regression analyses of moose abundance for the southern sub-region.

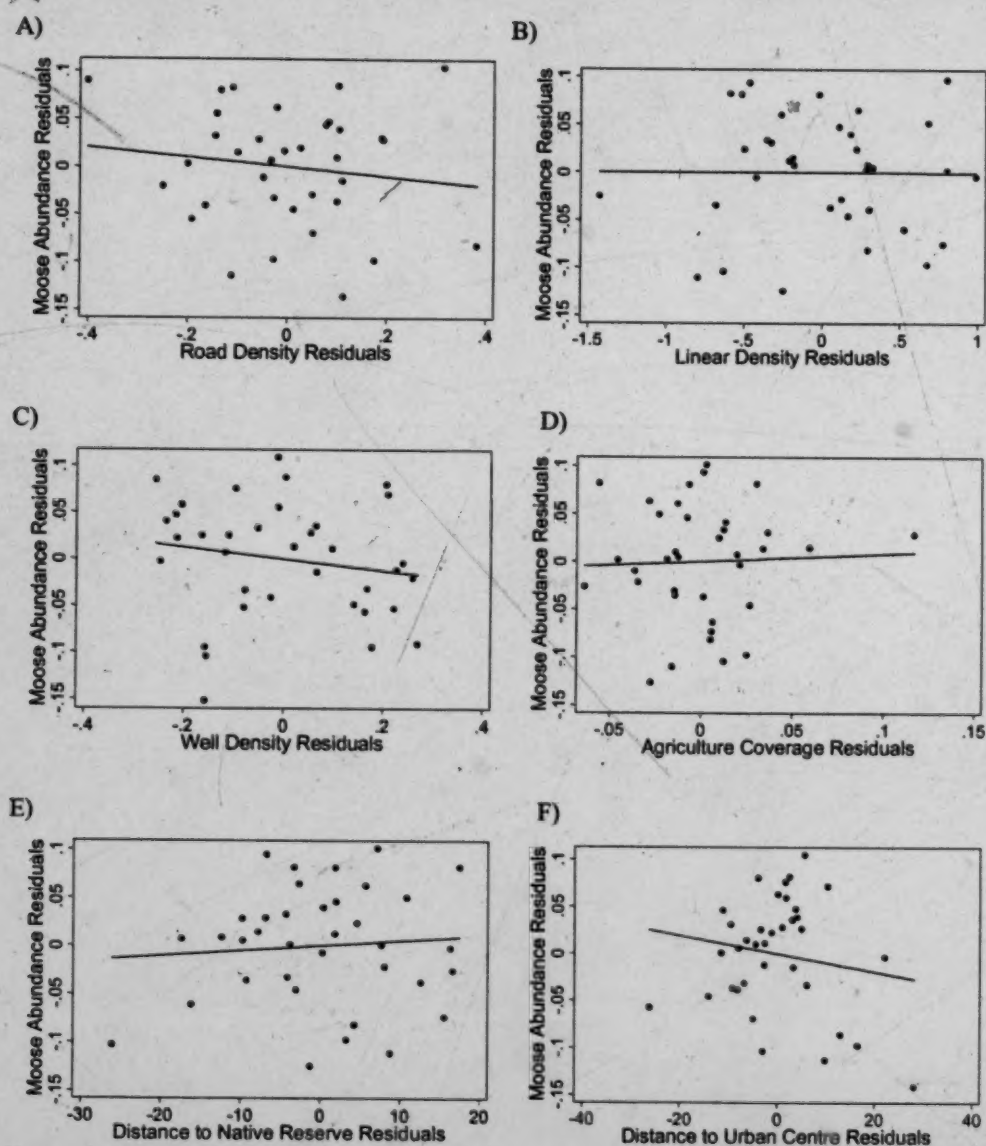


Figure 3.3: Results from regression analyses of moose abundance for the northern sub-region. Moose abundance derived from Alberta Sustainable Resource Development surveys (1998-2002). Partial regression plots shown. P-values, partial R^2 and coefficient listed below. A) Road density ($p=0.52$, $R^2=0.017$, $b= -0.05$). B) Linear density ($p=1.00$, $R^2<0.0001$, $b= -0.0001$). C) Well density ($p=0.37$, $R^2=0.028$, $b= -0.06$). D) Agricultural coverage ($p=0.83$, $R^2=0.002$, $b= 0.08$). E) Distance to native reserve ($p=0.67$, $R^2=0.008$, $b= -0.0005$). F) Distance to urban centre ($p=0.41$, $R^2=0.026$, $b= -0.001$). G) Distance to major highway ($p=0.66$, $R^2=0.008$, $b= -0.0004$). H) Cutblock coverage ($p=0.67$, $R^2=0.008$, $b= -0.30$).

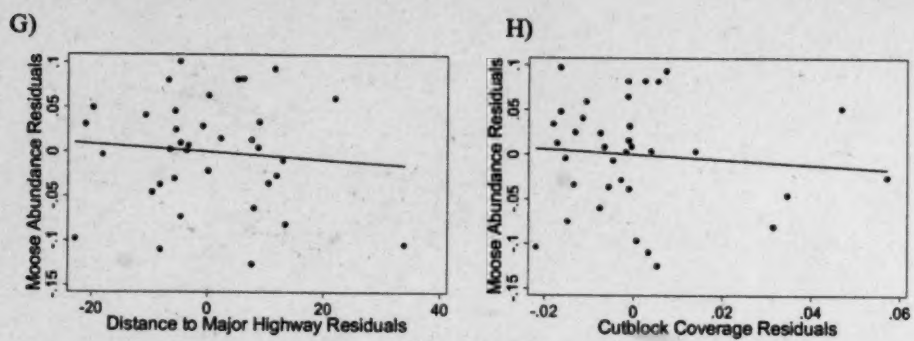


Figure 3.3 continued: Results from regression analyses of moose abundance for the northern sub-region.

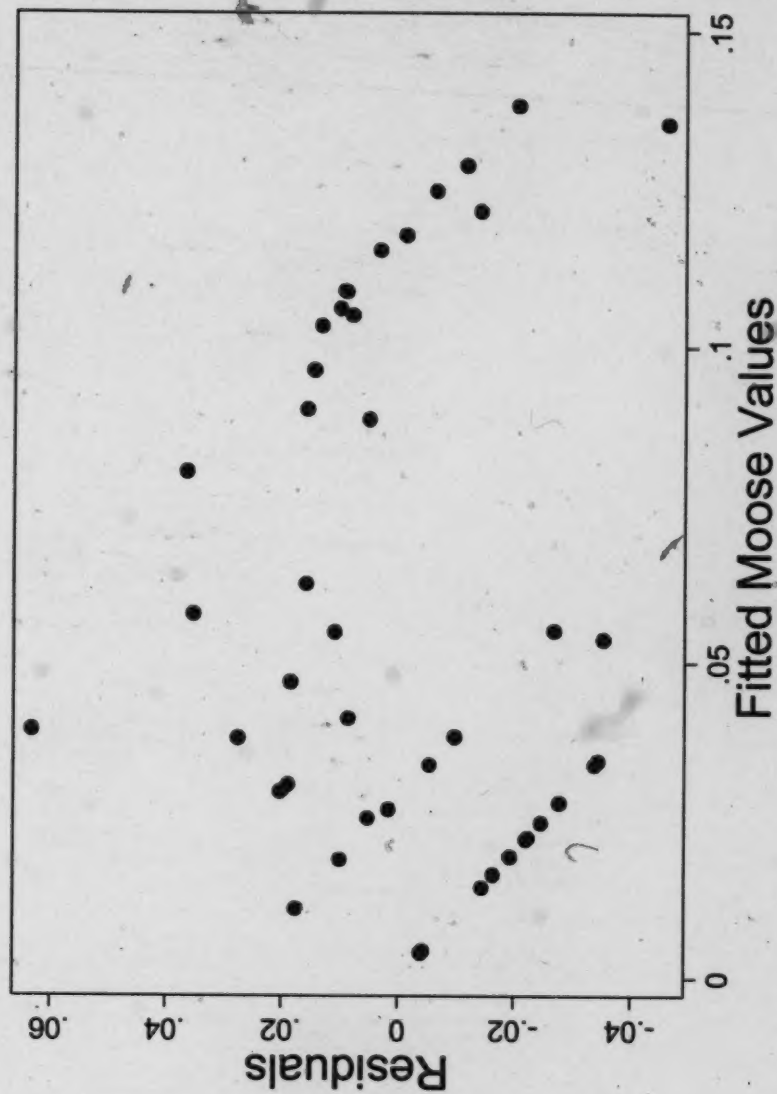


Figure 3.4: Residual plot of fitted moose values against residual values for the analysis of the relationship between moose abundance and landuse variables within sample sites in the southern sub-region of northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1998 to 2002.

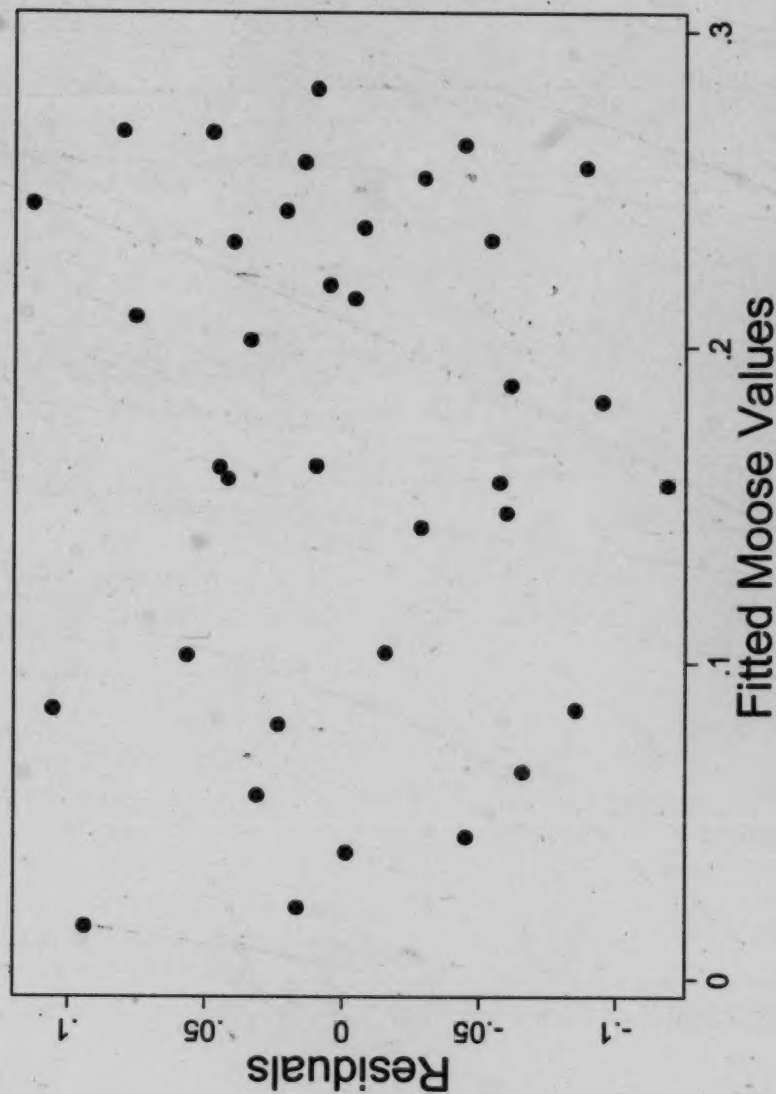


Figure 3.5: Residual plot of fitted moose values against residual values for analysis of relationship between moose abundance and landuse variables within sample sites in the northern sub-region of northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1998 to 2002.

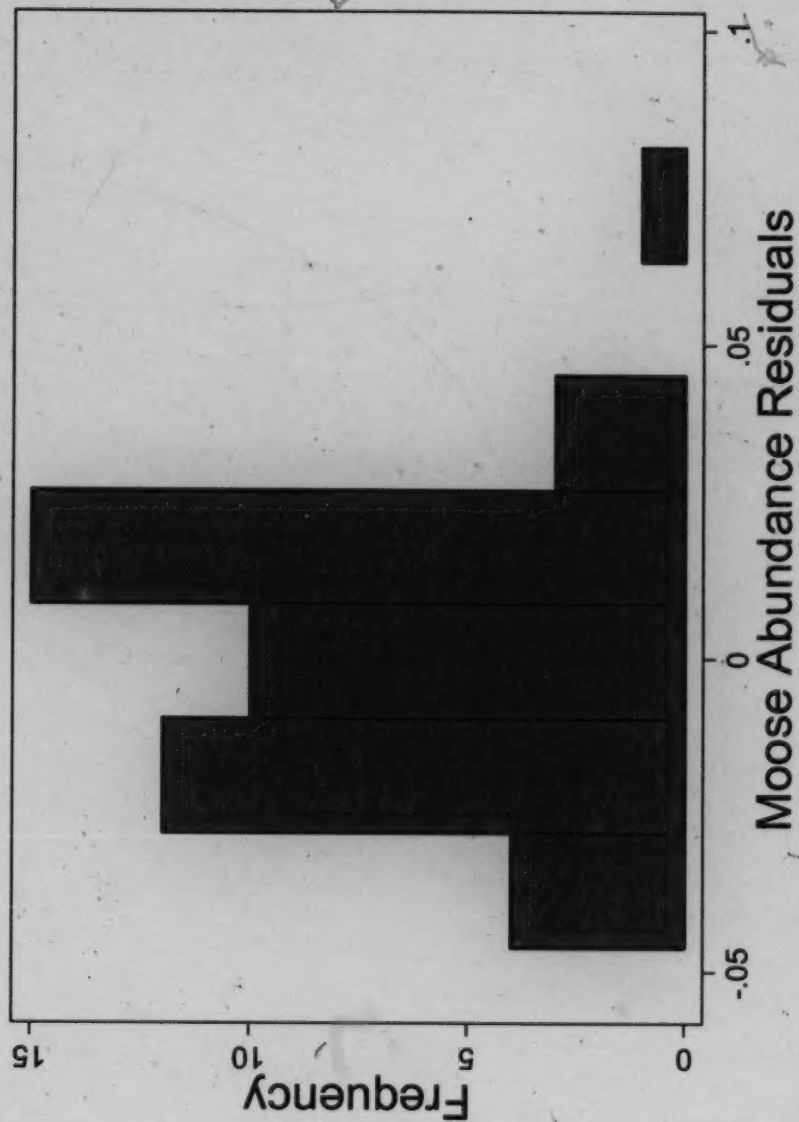


Figure 3.6: Histogram of moose abundance residuals for the analysis of the relationship between moose abundance and landuse variables within sample sites in the southern sub-region of northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1998 to 2002.

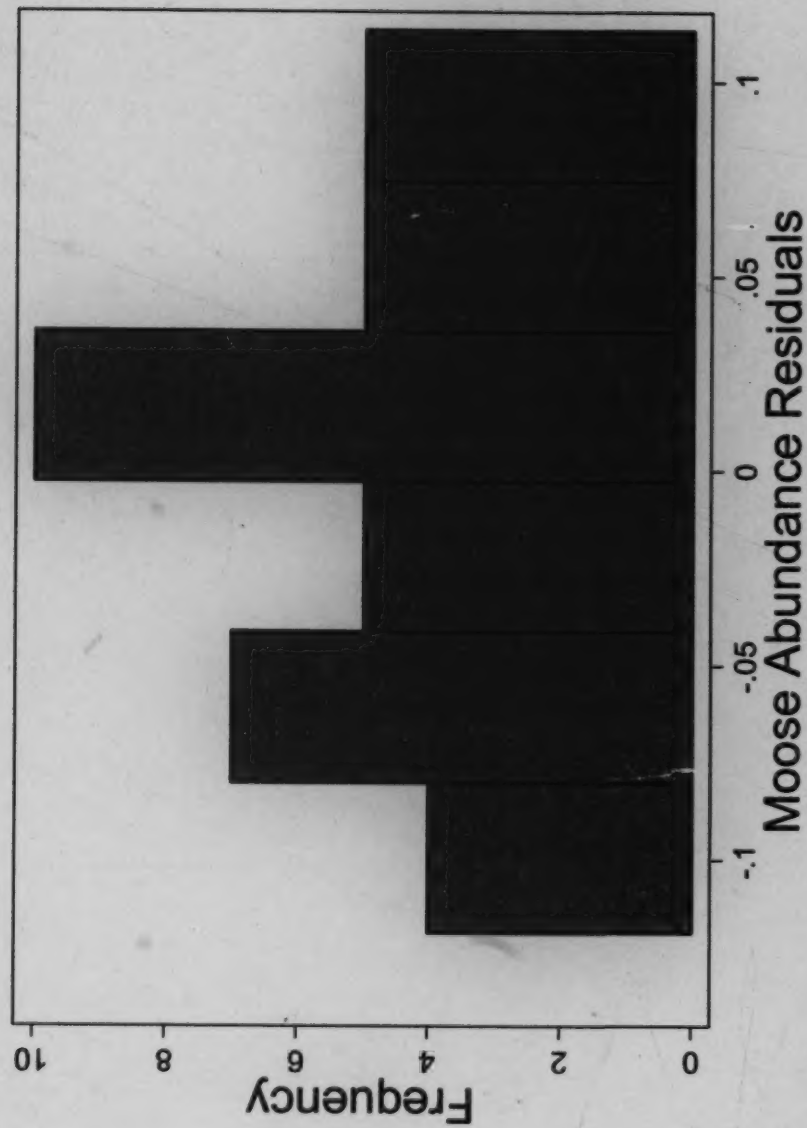


Figure 3.7: Histogram of moose abundance residuals for the analysis of the relationship between moose abundance and landuse variables within sample sites in the northern sub-region of northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1998 to 2002.

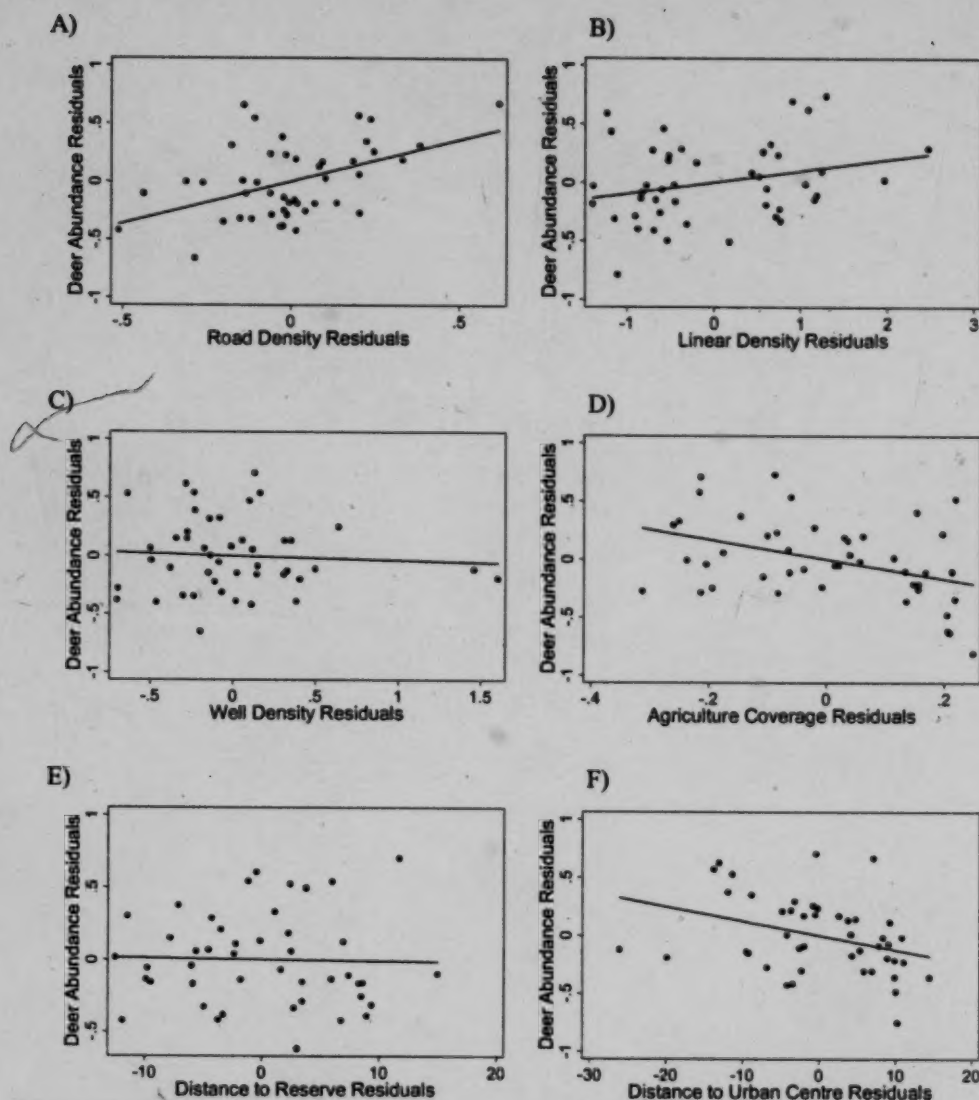


Figure 3.8: Results from regression analyses of white-tailed deer abundance for the southern sub-region. Deer abundance derived from Alberta Sustainable Resource Development surveys (1998-2002). Partial regression plots shown. P-values, partial R^2 and coefficient listed below. A) Road density ($p=0.005$, $R^2=0.220$, $b= 0.72$). B) Linear density ($p=0.09$, $R^2=0.075$, $b= 0.10$). C) Well density ($p=0.76$, $R^2=0.003$, $b= -0.04$). D) Agricultural coverage ($p=0.01$, $R^2=0.158$, $b= -0.85$). E) Distance to native reserve ($p=0.90$, $R^2=0.0006$, $b= -0.001$). F) Distance to urban centre ($p=0.04$, $R^2=0.118$, $b= -0.01$). G) Distance to major highway ($p=0.87$, $R^2=0.0008$, $b= -0.003$).

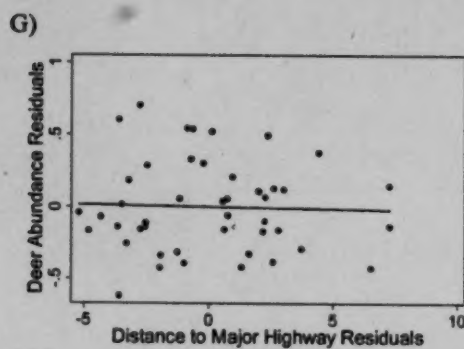


Figure 3.8 continued: Results from univariate negative binomial regression analyses of white-tailed deer counts for the southern sub-region.

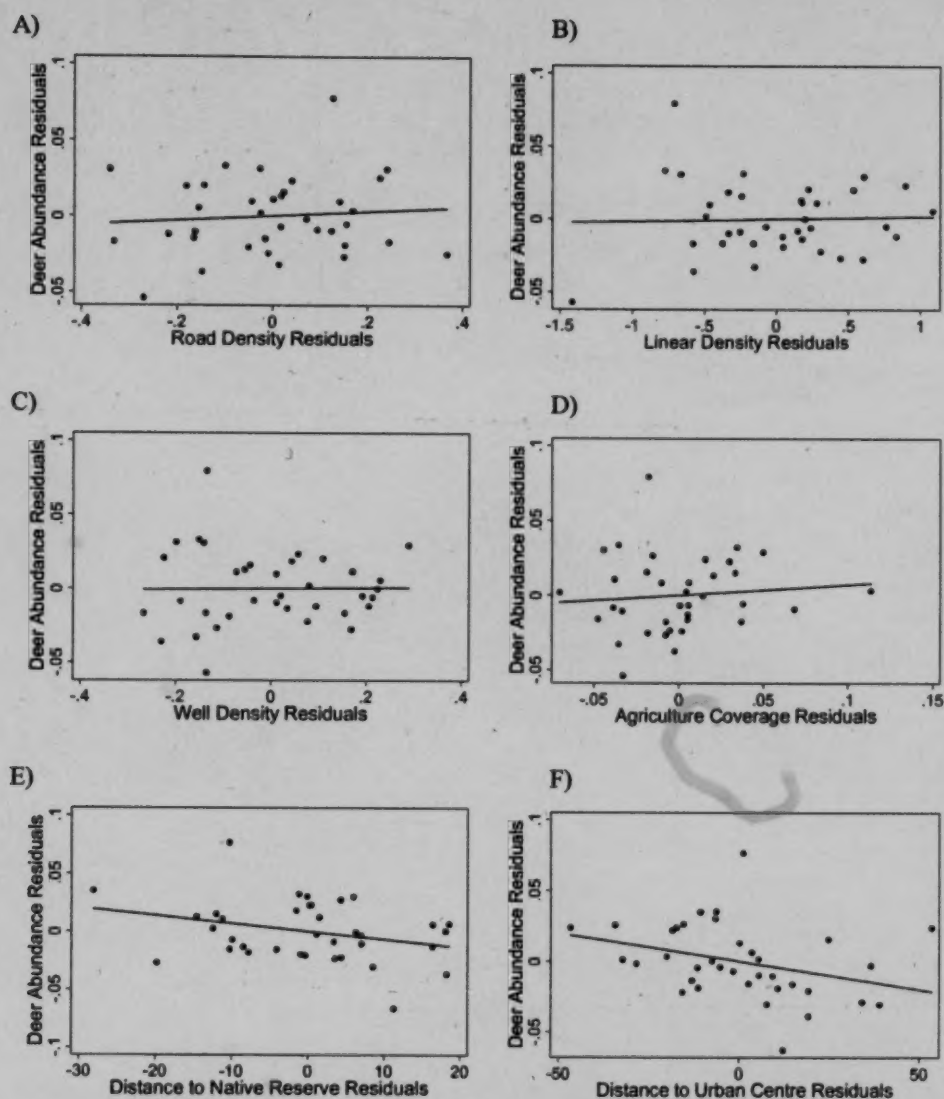
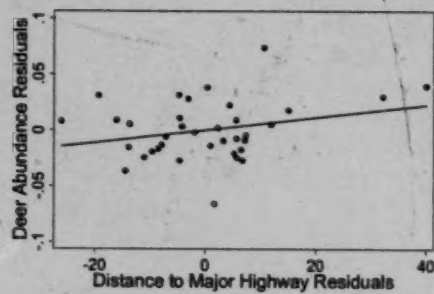


Figure 3.9: Results from regression analyses of white-tailed deer abundance for the northern sub-region. Deer abundance derived from Alberta Sustainable Resource Development surveys (1998-2002). Partial regression plots shown. P-values, partial R^2 and coefficient listed below. A) Road density ($p=0.64$, $R^2=0.009$, $b=0.01$). B) Linear density ($p=0.86$, $R^2=0.001$, $b=0.002$). C) Well density ($p=0.94$, $R^2=0.0002$, $b=0.003$). D) Agricultural coverage ($p=0.61$, $R^2=0.010$, $b=0.07$). E) Distance to native reserve ($p=0.13$, $R^2=0.084$, $b=-0.0007$). F) Distance to urban centre ($p=0.08$, $R^2=0.108$, $b=-0.0004$). G) Distance to major highway ($p=0.14$, $R^2=0.077$, $b=0.0006$). H) Cutblock coverage ($p=0.01$, $R^2=0.218$, $b=-0.63$).

G)



H)

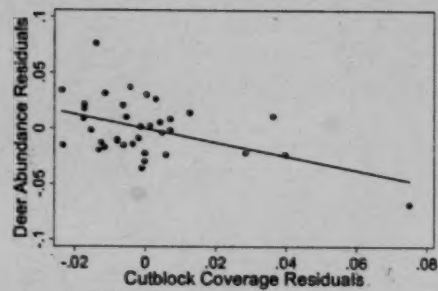


Figure 3.9 continued: Results from univariate negative binomial regression analyses of white-tailed deer counts for the northern sub-region.

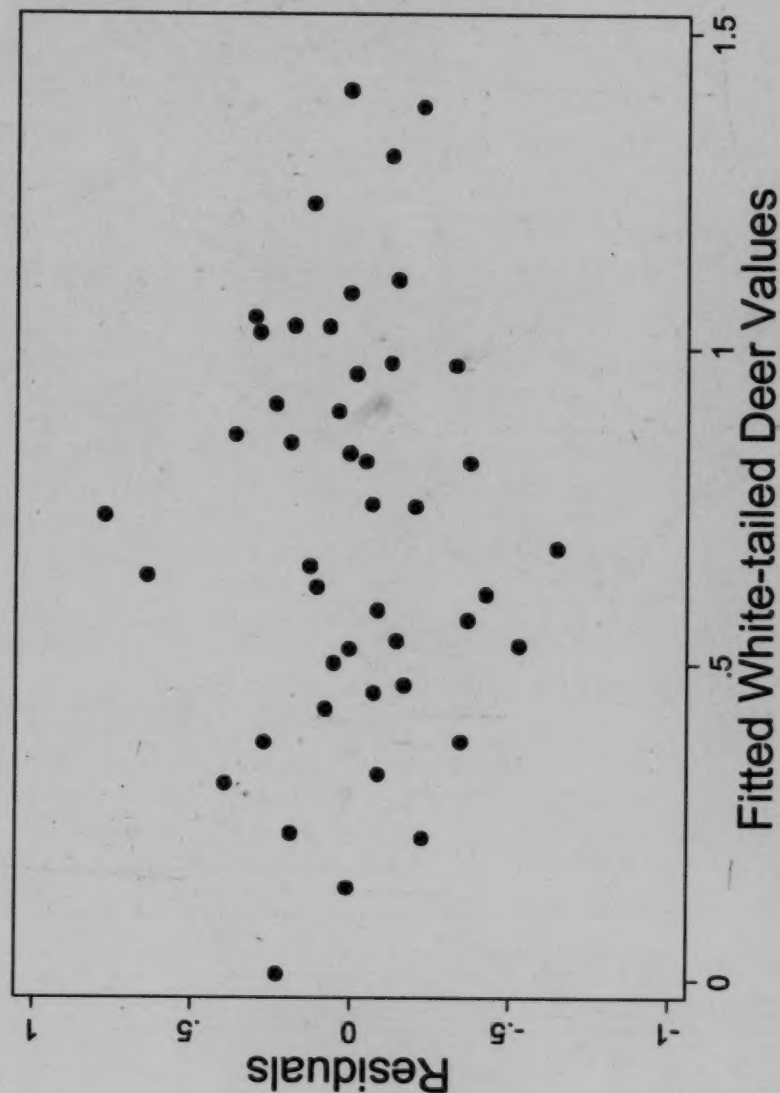


Figure 3.10: Residual plot of fitted white-tailed deer values against residual values for analysis of relationship between white-tailed deer abundance and landuse variables within sample sites in the southern sub-region of northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1998 to 2002.

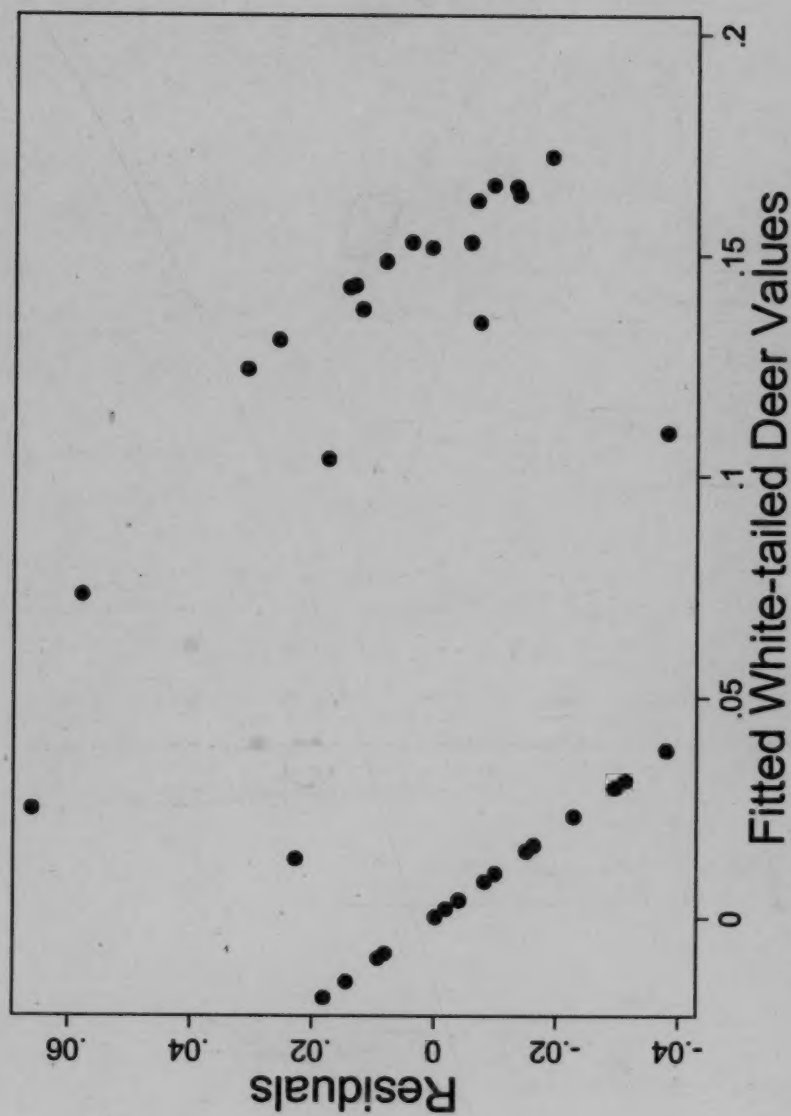


Figure 3.11: Residual plot of fitted white-tailed deer values against residual values for analysis of relationship between white-tailed deer abundance and landuse variables within sample sites in the northern sub-region of northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1998 to 2002.

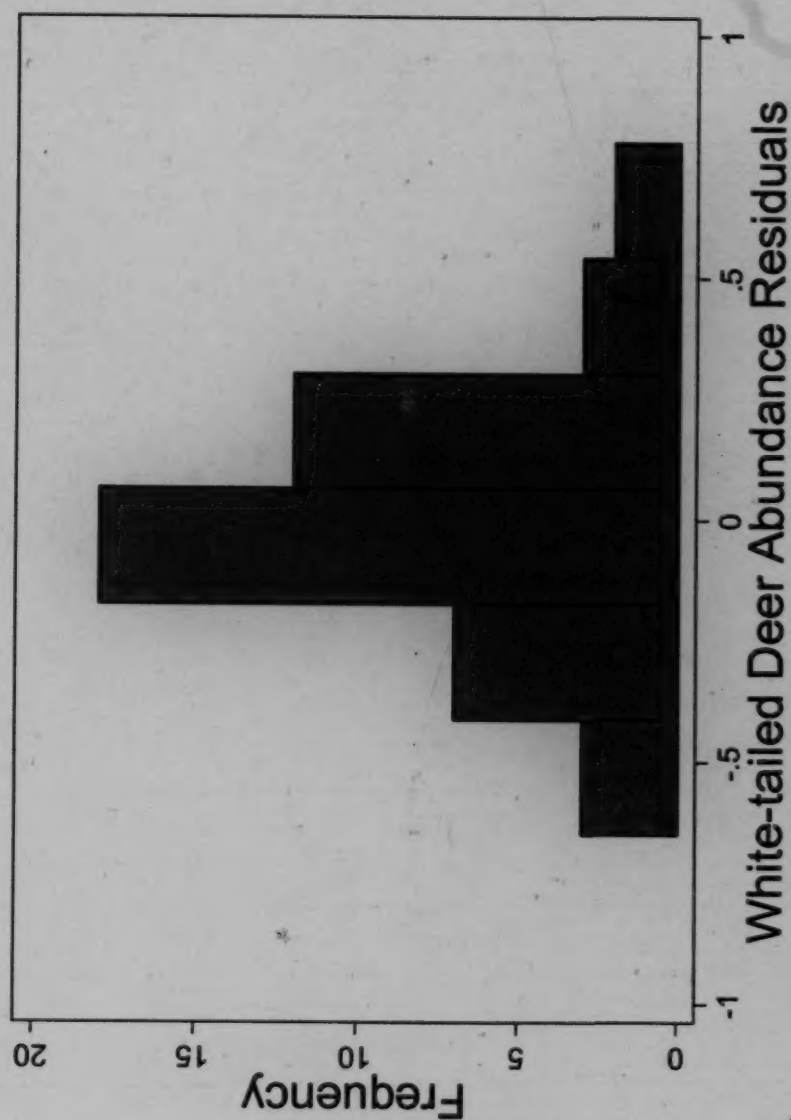


Figure 3.12: Histogram of white-tailed deer abundance residuals for the analysis of the relationship between white-tailed deer abundance and landuse variables within sample sites in the southern sub-region of northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1998 to 2002.

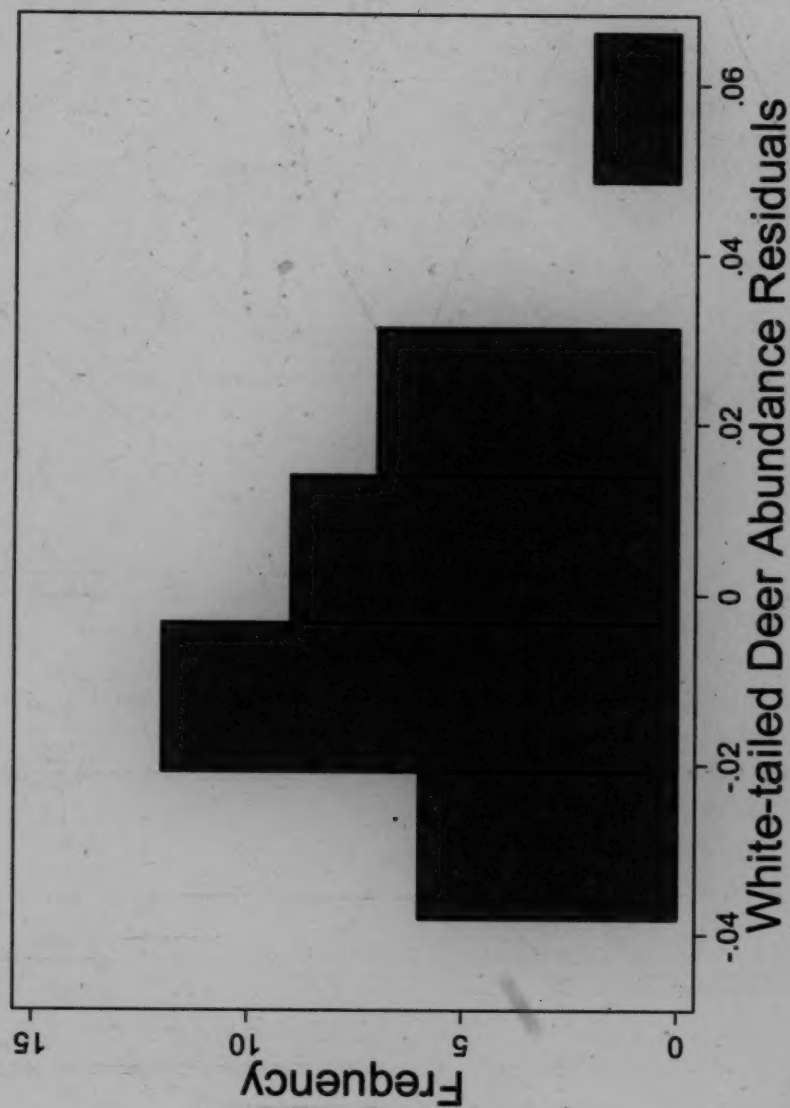


Figure 3.13: Histogram of white-tailed deer abundance residuals for the analysis of the relationship between white-tailed deer abundance and landuse variables within sample sites in the northern sub-region of northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1998 to 2002.

Table 3.1: Correlation matrix of landuse variables for all northeastern Alberta sample sites surveyed by Alberta Sustainable Resource Development from 1998 to 2002.

	Latitude	Road Density	Agriculture	Distance to Urban Centre	Distance to Major Highway
Latitude	1.00				
Road Density	-0.78	1.00			
Agriculture	-0.71	0.84	1.00		
Distance to Urban Centre	0.71	-0.66	-0.64	1.00	
Distance to Major Highway	0.81	-0.61	-0.53	0.77	1.00

Table 3.2: Median and range of percent area coverage of habitat and landuse variables within all northeastern Alberta sample sites surveyed by Alberta Sustainable Resource Development from 1998 to 2002. Regional data represents the values for townships across the northeast region of Alberta and is provided in brackets. Derived from Alberta Ground Cover Classification (2000).

Variable	Median	Range
Agriculture	0.22 (0)	0-0.86 (0-0.90)
Clearcuts	0 (0)	0-0.10 (0-0.32)
Closed Conifers	0.06	0-0.51
Closed Deciduous	0.03	0-0.28
Closed Mixedwoods	0.06	0-0.27
Open Conifers	0.03	0-0.29
Open Deciduous	0.03	0-0.29
Open Mixedwoods	0.03	0-0.14
Shrubs	0.006	0-0.07
Wetlands	0.08	0-0.46
Water	0.03	0-0.36

Table 3.3: Median and range of proportion of habitat and landuse variables within southern and northern sub-region sample sites in northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1998 to 2002. Northern data is provided in brackets. Derived from Alberta Ground Cover Classification (2000).

Variable	Median	Range
Agriculture	0.54 (0)	0.21-0.80 (0-0.20)
Clearcuts	0(0)	0-0.02 (0-0.10)
Closed Conifers	0.08 (0.22)	0.02-0.32 (0.03-0.45)
Closed Deciduous	0.08 (0.07)	0.006-0.34 (0.0003-0.24)
Closed Mixedwoods	0.11 (0.11)	0.03-0.51 (0.01-0.27)
Open Conifers	0.06 (0.09)	0.02-0.18 (0.002-0.29)
Open Deciduous	0.10 (0.06)	0.02-0.23 (0-0.29)
Open Mixedwoods	0.07 (0.03)	0.02-0.18 (0-0.11)
Shrubs	0.01 (0.006)	0.0001-0.11 (0.0004-0.05)
Wetlands	0.15 (0.15)	0.03-0.51 (0.03-0.46)
Water	0.08 (0.05)	0.0002-0.24 (0.007-0.38)

Table 3.4: Median and range of landuse and distance variables within all northeastern Alberta sample sites surveyed by Alberta Sustainable Resource Development from 1998 to 2002. Regional data for northeastern Alberta is provided in brackets. Derived from Alberta Base Features GIS layers (2000).

Variable	Median	Range
<i>Density Variables (km/km²)</i>		
Linear Density	1.72 (1.31)	0-4.50 (0-6.18)
Road Density	0.63 (0.44)	0-1.67 (0-2.60)
Wellsite Density*	0.39 (0.31)	0-2.75 (0.01-26.20)
<i>Distance Variables (km)</i>		
Distance to Major Highway	6.58	0-104.44
Distance to Native Reserve	51.88	0-114.07
Distance to Urban Centre	35.72	5.70-128.87

* Note: Wellsite density expressed in wellsites/km².

Table 3.5: Median and range of landuse and distance variables within southern and northern sub-region sample sites of northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1998 to 2002. Northern data is provided in brackets. Derived from Alberta Base Features GIS layers (2000).

Variable	Median	Range
<i>Density Variables (km/km²)</i>		
Linear Density	1.75 (2.42)	0-4.50 (0.13-4.38)
Road Density	0.95 (0.18)	0.22-1.67 (0-0.64)
Wellsite Density*	0.47 (0.32)	0.13-2.75 (0.04-0.90)
<i>Distance Variables (km)</i>		
Distance to Major Highway	6.58 (12.81)	0-104.44 (0-99.00)
Distance to Native Reserve	29.75 (59.70)	0-82.37 (17.75-96.07)
Distance to Urban Centre	27.77 (55.79)	5.70-44.46 (16.37-128.45)

* Note: Wellsite density expressed in wellsites/km².

Table 3.6: Correlation matrix of landuse, spatial and habitat variables for sample sites surveyed in the southern sub-region of northeastern Alberta by Alberta Sustainable Resource Development from 1998 to 2002.

	Longitude	Distance to Reserve	Shrub	Open Mixedwood
Longitude	1.00			
Distance to Reserve	-0.87	1.00		
Shrub	0.70	-0.59	1.00	
Open Mixedwood	0.53	-0.73	0.43	1.00

Table 3.7: Regression results for analysis of relationship between moose abundance and landuse variables within sample sites in the southern sub-region of northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1998 to 2002 (n=45; $p < 0.001$; adjusted $R^2 = 0.71$). 95% confidence interval range for coefficient provided in brackets. Expected change refers to the increase or decrease expected in moose/km² over the range of data for the region.

Variables	Coefficient	P>t	Expected Change
Longitude	2.6336 (0.0296 to 5.2376)	0.048	
Longitude ²	0.0118 (0.0002 to 0.0234)	0.047	
Well Density	-0.0172 (-0.0356 to 0.0012)	0.066	-0.05
Road Density	-0.0253 (-0.0582 to 0.0076)	0.128	-0.06
Agriculture Coverage	-0.0857 (-0.1510 to -0.0205)	0.012	-0.05
Closed Coniferous	-0.2781 (-0.5455 to -0.0107)	0.042	
Closed Deciduous	-0.2127 (-0.3962 to -0.0292)	0.024	
Water	-0.1372 (-0.3368 to 0.0623)	0.171	
Open Mixedwood	-0.3672 (-0.7876 to 0.0531)	0.085	
Open Deciduous	0.0482 (-0.2750 to 0.3715)	0.763	
Wetland	-0.0521 (-0.2274 to 0.1231)	0.549	
Constant	147.0727 (1.2844 to 292.8610)	0.048	

Table 3.8: Regression results for the analysis of relationship between moose abundance and landuse variables within sample sites in the northern sub-region of northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1998 to 2002 (n=36; p=0.0001; adjusted R²=0.61). 95% confidence interval range for coefficient provided in brackets. Expected change refers to the increase or decrease expected in moose/km² over the range of data for the region.

Variables	Coefficient	P>t	Expected Change
Latitude	-0.0576 (-0.1277 to 0.0124)	0.102	
Longitude	0.0072 (-0.0392 to 0.0536)	0.752	
Well Density	-0.1306 (-0.3020 to 0.0408)	0.129	-0.24
Linear Density	0.0052 (-0.0441 to 0.0546)	0.829	0.05
Distance to Native Reserve	0.0008 (-0.0013 to 0.0029)	0.457	0.18
Distance to Urban Centre	-0.0016 (-0.0040 to 0.0008)	0.174	-0.76
Closed Coniferous	-0.3183 (-0.6777 to 0.0411)	0.080	
Closed Mixedwood	-0.6027 (-1.4114 to 0.2061)	0.137	
Water	-0.2108 (-0.7454 to 0.3239)	0.424	
Open Coniferous	0.0075 (-0.6846 to 0.6997)	0.982	
Constant	4.4166 (-2.1621 to 10.9954)	0.179	

Table 3.9: Regression results for analysis of relationship between white-tailed deer abundance and landuse variables within sample sites in the southern sub-region of northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1998 to 2002 (n=45; $p < 0.001$; adjusted $R^2 = 0.50$). 95% confidence interval for coefficient provided in brackets. Expected change refers to the increase or decrease expected in deer/km² over the range of data for the region.

Variables	Coefficient	P>t	Expected Change
Latitude	-0.4456 (-0.8604 to -0.0308)	0.036	
Well Density	-0.1954 (-0.3979 to 0.0070)	0.058	-0.67
Road Density	0.3776 (-0.0128 to 0.7680)	0.058	0.99
Agriculture Coverage	-1.2398 (-1.8560 to -0.6236)	<0.001	-1.66
Distance to Urban Centre	-0.0108 (-0.0200 to -0.0015)	0.024	-0.73
Water	2.7409 (0.8762 to 4.6055)	0.005	
Closed Deciduous	1.8547 (0.6343 to 3.0751)	0.004	
Constant	25.2343 (2.4603 to 48.0084)	0.031	

Table 3.10: Regression results for the analysis of relationship between white-tailed deer abundance and landuse variables within sample sites in the northern sub-region of northeastern Alberta surveyed by Alberta Sustainable Resource Development from 1998 to 2002 (n=36; $p < 0.001$; adjusted $R^2 = 0.86$). 95% confidence interval for coefficient provided in brackets. Expected change refers to the increase or decrease expected in deer/km² over the range of data for the region.

Variables	Coefficient	P>t	Expected Change
Latitude	-0.0456 (-0.0710 to -0.0202)	0.001	
Longitude	-0.0151 (-0.0362 to 0.0060)	0.153	
Cutblock Coverage	-0.3940 (-0.9217 to 0.1338)	0.137	-0.07
Road Density	0.0367 (-0.0216 to 0.0950)	0.207	0.03
Distance to Native Reserve	-0.0005 (-0.0014 to 0.0004)	0.257	-0.07
Distance to Urban Centre	-0.0007 (-0.0011 to -0.0002)	0.005	-0.10
Distance to Major Highway	0.0001 (-0.0009 to 0.0010)	0.909	0.01
Shrub	0.1058 (-1.2198 to 1.4313)	0.871	
Closed Deciduous	0.1194 (-0.0905 to 0.3294)	0.252	
Open Deciduous	0.1895 (0.0073 to 0.3717)	0.042	
Constant	0.9466 (-2.2828 to 4.1760)	0.551	

General Conclusions and Implications

Research Summary and Conclusions

The overall intent of this research was to examine changes in ungulate counts and distribution, as well as the relationships between ungulates and cumulative impacts in northeastern Alberta. The objectives of my study were 1) to determine the spatial and temporal changes in moose (*Alces alces*) and white-tailed deer (*Odocoileus virginianus*) counts in northeastern Alberta over the last 30 years, while taking into consideration the effects of survey logistics and 2) to determine recent relationships between cumulative impacts and moose and white-tailed deer abundance in northeastern Alberta. Considering the trends in ungulate counts provided a basis for pursuing the relationships between cumulative impacts and ungulates. While moose counts appeared to decline over the 33 year time frame (1969 to 2001), white-tailed deer exhibited a northward expansion in distribution and increase in counts. These observed trends were apparent after controlling for survey variables.

The analysis of the relationships between ungulates and cumulative impacts indicated that moose exhibited a negative relationship to the cumulative impacts arising from the individual disturbance of agriculture. In addition, moose were negatively related to the additive effects arising from agriculture and well density. All of these relationships were observed in the southern region. Though these relationships resulted in relatively small changes in moose abundance, if the intensity of agriculture and well density increases, it seems likely that moose declines observed in Chapter 2 will continue. Future projections of wellsite density within regions of the northeast predict that the number of new conventional oil and gas wells will continue to increase until 2040, when in-situ oil sands wells will become the predominant source of new wells (Schneider 2002). According to future projections, there will also be a progressive reduction in the forest land base, with the remaining forest becoming progressively younger and more fragmented (Schneider 2002). This habitat conversion would likely prove unfavourable for both moose given the

relationship to agricultural coverage. However, the moose declines observed in Chapter 2 are not due to the expansion of landuse disturbance alone, since the observed moose responses to cumulative impacts were weak and limited to the agricultural zone, while the declines observed in Chapter 2 extended throughout the northeast region. Therefore, further research into the factors contributing to moose declines is warranted.

White-tailed deer exhibited a negative relationship to the cumulative impacts arising from the individual disturbances of agriculture and cutblocks and a positive relationship to cumulative impacts arising from the individual disturbance of road density. White-tailed deer were also related to the additive cumulative effects of well density, road density and agricultural coverage. However, as with moose, with the exception of agricultural coverage, the relationships resulted in relatively small changes in white-tailed deer abundance. As well, white-tailed deer abundance was higher closer to urban centres. Given these results, it is difficult to determine if the expansion and increase in white-tailed deer observed in Chapter 2 are related to cumulative effects, as the population trends seem to contradict that which would be expected given the negative relationships observed in Chapter 3. However, white-tailed deer abundance did exhibit a positive relationship to road density and in some regions of the northeast, road density is projected to increase to seven times what it is today (Schneider 2002). Roads and low levels of agricultural coverage may provide vectors for white-tailed deer increase in abundance since they adapt readily to both open and wooded habitats (Stelfox and Stelfox 1993). Contrarily, given the progressive reduction in the forest land base noted above, deer may be expected to decline, though this clearly has not yet occurred. These contradictions require that further research is conducted into the causes of white-tailed deer population increases.

Management Recommendations

The relationships noted between ungulates and cumulative impacts raise concerns about potential future implications of landuse on ungulate abundance and indicate the importance in

managers considering landuse change in the future. Increasing future human impacts in northeastern Alberta will likely result in a continuing downward trend in moose abundance. However, the relationships between moose, white-tailed deer and individual, additive and multiplicative cumulative effects need to be further examined to confirm the results I observed and to determine the causal factors contributing to these relationships, which may help to identify ways of mitigating the effects. As well, further research into additional factors lending to the changes in ungulate abundance and distribution need to be conducted. Additional factors that may be considered include the influence of climate, predation and fire. Furthermore, managers need to be conscious of both the observed northward expansion of white-tailed deer and declines in moose and the potential implications these could hold for both ecosystem dynamics and society.

Literature Cited

- Schneider, R.R. 2002. Alternative Futures: Alberta's Boreal Forest at the Crossroads. The Federation of Alberta Naturalists, Edmonton, Alberta, Canada. 152 pp.
- Stelfox, J.B. and J.G. Stelfox. 1993. Distribution. Pp. 45-61 in Stelfox, J.B., ed. Hoofed Mammals of Alberta. Lone Pine Publishing, Edmonton, Alberta, Canada. 241 pp.